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ABSTRACT

One of the clear findings of recent research on the learning of science has been that students who have completed science courses commonly use conceptions held before instruction to interpret natural phenomena. This paper reports on a study of conceptual change in mechanics with particular concern with the nature of student awareness of any conceptual change. Metacognition and constructivist views of learning were considered. This study focused on three purposes: (1) to investigate the impact on student performance on related content in the following year of any conceptual exchange; (2) student perception in the subsequent year of the nature, purpose and value of the instruction aimed at conceptual change; and (3) the effect of laboratory strategies used in more usual educational contexts to promote conceptual change. The study involved 46 year 10 students one year, and 110 year 11 students the next year, including 28 from the previous year's group, in Victoria, Australia. The study concludes that: the approaches used in year 10 to promote conceptual exchange had some utility; year 10 instruction has an effect on year 11 performance; and year 11 perceptions of the value of the year 10 experience varied. This reinforces the need to explicitly help students understand and control their own learning as a major contributor to developing their own understanding. (CW)

Some long-term effects of uninformed conceptual change

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Paper presented at the annual meeting of the American Educational Research Association, New Orleans, April 1988.

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Some long term effects of uninformed conceptual change.

Introduction

One of the clear findings of recent research on the learning of science has been that students who have completed science courses commonly use conceptions held before instruction to interpret natural phenomena. This is often the case even when students have passed conventional tests. This has led to an obvious concern with conceptual change in students; a concern with exploring alternative approaches to instruction, assessment, etc. which might better promote an acceptance and understanding of the concepts of science.

This paper reports a study of conceptual change in mechanics, with particular concern with the nature of student awareness of any conceptual change. It grows out of previous research in the area of mechanics by Champagne, Gunstone and Klopfer (1985). One group used in that research comprised science graduates (biology and chemistry majors) who were enrolled in a one year high school teacher training course. Substantial conceptual change was achieved with most members of that group. One major factor in that change was a considerable development in understanding of their own learning by members of the group. This role of metacognitive issues in the conceptual change achieved in that study was one of the precusors to the present research. Hence metacognition and constructivist views of learning are briefly considered.

Constructivism and Metacognition

Much of the science learning research referred to above has been based on a constructivist view of learning, a view which holds that individuals idiocyncratically construct their own meanings for sensory inputs. Wittrock's generative model of learning (Osborne & Wittrock, 1983; Wittrock, 1974) is one of the more influential articulations of the constructivist view.

Constructivists hold that the alternative conceptions so ...

commonly found among science students are the outcomes of this personal construction process. The difficulties shown to exist when attempts are made to have students abandon an alternative conception and accept a science conception are sometimes seen as an inevitable consequence of the alternative conception being a personal construction of the reality the student experiences. Pines and West (1986), in an analysis of research on students' ideas and beliefs, argue that this research can be interpreted in terms of two sources of knowledge: knowledge spontaneously acquired from interactions with the environment and knowledge acquired formally through the intervention of school. These two sources can be in conflict, be congruent, or exist alone. Pines and West take this analysis further to argue that the extent to which conflict exists between the two sources should influence the focus of the learning which is promoted in school science. It is only in cases of major conflict that the focus should be on abandoning one conception and accepting another. This they term "conceptual exchange" (p.593).

The present study, and the research which led to it, certainly involves conflict between sources of knowledge. Hence the focus of the work is on conceptual exchange. Pines and West (1986) point to the difficulty of determining if conceptual exchange has taken place. Differentiating between genuine exchange, and the rote acquisition of compartmentalized formal knowledge without abandoning conflicting spontaneous knowledge, is most difficult. This issue has contributed to the nature of the present study, although no claims are made that a successful approach to such differentiation has been achieved.

My thinking about conceptual exchange has been influenced for some time by the notion that ideas can be Intelligible, Plausible, or Fruitful (Hewson, 1981; Posner et al., 1982). That is, that dissatisfaction with an existing conception is far from sufficient to cause the abandoning of that conception and the acceptance of a new conception. In addition, the new conception must be intelligible (i.e. ...

be understandable) and plausible (i.e. appear reasonable) and fruitful (i.e. offer something of value) for it to be accepted. The focus of much science teaching is only to make concepts intelligible to students (Gunstone, in press), with even plausibility being too rarely considered. However it is fruitfulness, that is the learner perceiving some advantage to him or her in adopting the new conceptualization, which is necessary for conceptual exchange: in essence, does the new conception offer the learner something the learner values which the old conception does not?

Fruitfulness is complex, and hard to achieve. One useful way to consider the idea is in terms of external and internal fruitfulness (Gunstone, in press). By these I mean fruitfulness resulting from factors external to the student, such as the nature of the assessment the student will undertake, or from factors internal to the student, such as considering whether or not a new idea gives a more powerful explanatory system to apply to the world. Of these two, clearly internal fruitfulness is far more likely to promote conceptual exchange but far harder to achieve. Its achievement is closely intertwined with students understanding and controlling their own learning.

The previous work from which the present study has emerged, attempts to produce conceptual exchange in mechanics with science graduates, has already been mentioned. In this previous study one of the most powerful indicators of conceptual exchange was the considerable increase in metacognition among the graduates. By metacognition I mean student directed formative evaluation of their own learning. Examples of metacognitive statements by the graduates are given in Champagne, Gunstone & Klopfer (1985, pp.175-6).

This substantial increase in metacognitive behaviour was closely related to internal fruitfulness. The subjects in the study were only a short time away from teaching high school students the concepts with which they themselves were grappling. Hence there was

...

considerable internal fruitfulness involved, not only in terms of mechanics but also in terms of understanding aspects of learning. In that study then, internal fruitfulness was relatively easily achieved. One motivation for the present study was to explore this issue in a more usual context.

The Purposes of this Study

The present study had [illegible] broad purposes, all arising from the work with graduates discussed above. That research focussed on immediate outcomes, i.e. at the conclusion of the instructional sequence graduates were found to have adopted a Newtonian interpretation of forces and motion. The present study explored longer term effects of such an instructional sequence from two perspectives, both of which have been alluded to in the previous section:

(i) What impact on student performance on related content in the following year would any conceptual exchange produce? (In other words, if conceptual exchange was achieved, would it result in the external fruitfulness of higher grades in subsequent learning?)

(ii) How would students in this subsequent year perceive the nature, purpose and value of the instruction aimed at conceptual exchange? (In other words, if conceptual exchange was achieved, would it result in the internal fruitfulness of increased metacognitive awareness?)

The third purpose for the study reflects the fact that the previous research with graduates had taken place in a form of laboratory context (that is with students not enrolled in a science or physics course) and with a group with atypical motivation to learn. The present study was undertaken with intact school classes as part of their science or physics courses. Hence the third, and more basic, purpose of the study:

(iii) Will strategies used previously in laboratory contexts promote conceptual change in more usual educational contexts?

The Context of the Study

In the state of Victoria, high schools are six-year institutions (grades 7 - 12). All students undertake a general science (integrated science) course in years 7 - 10, and some elect to undertake specialised science studies in grades 11 and 12. Physics is one of these 2 year specialist science courses.

There is an exception to this structure in one provincial city where a single senior high school (years 11 and 12 only) exists, with all other high schols being junior high schools (years 7 - 10) feeding into the senior school. The study proper took place in this location. Two year 10 classes in one of the junior schools spent four weeks of their science course undertaking the instruction designed to promote conceptual exchange in mechanics. The nature of the instruction and the data collected are given below. A total of 46 year 10 students was involved. In the following year, 28 of these students elected to study physics in the senior high school. These 28 were randomly distributed across 5 year 11 physics classes containing a total of 110 students at the time of data collection. This random distribution was the usual practice of the school and not influenced in any way by the researcher. This can be stated with total confidence, as no contact of any form was made with the senior high school until mid-way through the year 11 course. At this time mechanics had been completed in the year 11 program.

This location for the research provides a form of pseudo-controlled investigation. The nature of the year 10 program in all other feeder schools was established. None had any similarity with the style and focus of the instruction used with the year 10 groups in this study. Hence the conceptual exchange oriented instruction was unique to the 28 students from that school. These 28 students then became inseparable from the other 82 year 11 students as far as the senior high school was concerned. There is no evidence that any year 11 physics teacher was aware of the year 10 experience. Hence it is most unlikely that the 28 students from the year 10 classes who undertook instruction focussing on conceptual exchange were treated in any way differently in year 11. This probable uniform treatment of all year 11 students was increased further by the lack of contact of any form with the senior high school until mid-year.

A trial of the year 10 instruction was undertaken with one year 10 class in a year 7 - 12 high school in Melbourne prior to beginning in the junior high school. No changes were judged necessary to the general thrust of the instruction. Data were collected from the 21 students in this class and the 6 who elected to study physics in the following year. Some reference to these trial data is made below.

In the presentation of data below, the following names are used for the three schools: the year 7 - 10 and 11 - 12 schools are called Junior High School and Senior High School respectively, and the year 7 - 12 school used to trial the instruction is called Single High School.

The year 10 instruction

The instructional sequence used with the year 10 classes was drawn from the sequence used with science graduates in previous research (Champagne, Gunstone & Klopfer, 1985). The adaptation of this previous sequence was done by the researcher and a research assistant. The research assistant had substantial physics teaching experience at both high school and college levels, and was the person who conducted the year 10 classes. The researcher was an observer of most of the trial classes at Single High School.

The instruction made consistent use of an interpretative teaching approach (Barnes, 1976). Of particular importance in this interactive and strongly discussion-based approach to learning physics were a focus on the concept of normal reaction and considerable use of the Demonstrate - Observe - Explain (or Predict - Observe - Explain) ...

teaching strategy (Champagne, Klopfer & Anderson, 1980; Gunstone & White, 1981). The focus on normal reaction involved a modification of the approach of Minstrell (1982). Its importance, as has been argued elsewhere (Gunstone & Shipstone, 1984), lies in the fact that the origins of conceptual problems for many students are more in the assertions of physics than in the conceptions of students. In particular, the failure of the arguments presented in physics to recognize distortion in surfaces involved in exerting normal reaction forces causes great difficulty for many students. Acceptance of the existence of this distortion enables many students to accept the concept of normal reaction and abandon alternative conceptions such as "the table is rigid, so things can't fall through it". The relative ease of this process with many students is a reflection of it being the perception of the physics conception which changes much more than their own conception. In the Demonstrate - Observe - Explain (DOE) strategy, predictions of the effect of some change on a given situation are asked for, and students' explanations of that change are sought. The change is then undertaken, and student observations are obtained. Discussion is then used to try firstly to come to a common observation (often a difficult issue; see Gunstone & Champagne, 1988) and secondly to reconcile differences between prediction and observation. As with the previous research with graduates, there was a strong focus on falling bodies in the DOEs.

No attempt was made during the instruction to focus students on metacognitive issues of any form.

An outline of the instruction is given in Appendix 1.

Data collected

In year 10 the following data were collected.

- Written responses to a number of tasks during instruction.
- Brief written reactions to the instructional approach, half way through and at the end. Questions asked whether students felt

their ideas about forces had been changed, what specific things contributed to any changes, whether there were any negative feelings about the approach, and for other comments.

- Some classroom transcripts.
- Performance on a test probing conceptual exchange in the areas on which the instruction focussed. Questions involved showing individual forces and total force on a ball thrown along a number of trajectory (adapted from Viennot, 1979, p.23), indicating direction of total force at three different positions for a ball thrown straight up (Osborne & Freyberg, 1985, p.45), showing all forces acting on a person standing on a chair cleaning leaves from the gutter of a house and on a leaf sitting on the chair after the person had left, forces on a golf ball, and a DOE involving objects suspended on a pulley (Gunstone & White, 1981). Explanations of answers were asked for.
- Performance on a second, more conventional test used to generate student grades in a manner acceptable to the schools.

The year 11 data involved the following:

- Performance on the mid-year physics exam given by Senior High School, for all 110 year 11 students (and similarly for Single High School year 11 physics). In both cases the exam covered kinematics and light as well as mechanics. One of the penalties of the planned lack of contact with Senior High School until mid-year was that data about student performance on the subset of questions involving mechanics could not be obtained. Thus total scores for the whole examination had to be used.
- Performance on a conceptual mechanics' test containing some questions of parallel form with the year 10 conceptual test and some different, again for all 110 year 11 students at Senior High School.
- Interviews with the year 11 physics students who had experienced the conceptual exchange focussed instruction in year 10. All interviews were undertaken by a second research assistant who had had no previous contact with any of the students. The interviews

explored the students' recollections of the year 10 experience and other year 10 classes; their perceptions of the purpose of the year 10 experience, differences in approach between this and other year 10 classes, and any preference they had for one or other of the approaches; their perceptions of the value or otherwise of the year 10 exercise to their year 11 physics learning. Students were interviewed in groups arranged by the school. The nature and advantages of the group interview have been elaborated by Van Galen, Hare and Noblit (1986). It is particularly appropriate in contexts such as this, where the purpose is to explore what students see as clearly opinion. It is less appropriate where students are likely to perceive "right" and "wrong" in answers. The 6 Single High School students were interviewed in 2 groups of 3. Of the 28 Senior High School students, 2 were absent on the arranged day. One of these subsequently wrote answers to the questions on the prepared interview schedule; the other could not be contacted. The remaining 26 were interviewed in groups ranging in size between 3 and 5. The tape recorder malfunctioned for one group of 3. Hence, for the 28 students, interview transcripts involving 23 were obtained and one gave written comments.

Results

The focus here is on the results from Junior High School and Senior High School, both because the Single High School instruction was treated as a trial and because the year 11 physics teacher in that school was aware of the nature and purpose of the year 10 instruction.

Year 10

Conceptual exchange: The data suggest that conceptual exchange was undertaken by a number of students. Analysis of the conceptual test answers shows that 37 of the Junior High School students used normal reaction forces in giving explanations which were correct in terms of physics for both the person and the leaf on a chair; 1 student may have been using appropriate physics, but wrote answers which were not unambiguously appropriate; 6 failed to use normal reaction appropriately for one or both questions; 2 were absent for the test.

The DOE used on the test involved a bucket and a block of wood connected by a cord placed on a pulley. The two objects were at rest and at the same level. Students described the forces on the objects, then the block was pulled down and held at a lower position. Students predicted what would happen when the block was released, gave reasons for predictions, wrote what they observed when the block was released, and reconciled prediction and observation (if appropriate). The description of forces was done well by most students. The proportions predicting movement up, movement down and no movement on release were similar to the distribution of predictions found previously among first year university physics students (Gunstone & White, 1981). More impressive, in terms of conceptual exchange, were reconciliations among those who predicted movement. An acceptance of the observation, and use of appropriate Newtonian concepts to explain the flaw in a prediction of movement, were more frequent among these year 10 students than among the first year university physics students.

The questions about forces on balls in flight also showed that a number of students were using a Newtonian view to interpret these situations. This was relatively less common for these questions than for the preceding two, a result not surprising given the substantial evidence of tenacity of alternative conceptions in this case. (See, for example, Ameh & Gunstone, 1988 where details are given of the alternative conceptions applied to forces on balls in flight by a substantial proportion of a large sample of qualified high school science teachers).

Evidence of conceptual exchange is also found in the written responses to DOE tasks used through the instructional sequence. By the end of the instruction most students were applying Newtonian perspectives to the analysis of falling objects.

In passing, it is interesting to note that the extent of conceptual exchange among those who subsequently elected to study physics in year 11 is little different from that among those who did not. This finding is similar to that of a different study involving year 10 science and year 11 physics students (De Jong & Gunstone,1988). A possible interpretation is considered later in this paper.

Reactions to the instruction: Most reaction was very favourable, with the specific events of DOEs with metal and rubber balls dropped from about 2 metre and, later, about 10 metre, being commented on often. The DOE requirement of prediction (and hence thinking) before the experiment was also widely commented on, and, in most cases, favourably. There was some negative reaction to the lack of traditional, hands on laboratory work, a concern with a lack of "doing things ourselves". On the other hand, some students commented positively on the greater intellectual activity in the DOE structure, as compared with traditional laboratory work.

One interesting feature of the reaction sheets was the way that existing student conceptions of what teaching and learning should be intruded on their judgements. In a number of cases students made informed and positive comments about what they had learned and why they believed they had learned this, but then concluded with negative reactions which reflected views of what "real" teaching and learning should be. For example, a student from Junior High School who was positive about what had been learned and who then wrote "this sort of class leaves to (sic) much of the work unclear. The textbook and notes method means that at least you know what you're supposed to learn". Another from the same school responded as follows: (Have your ideas about forces been changed...?) "Yes great. These are mostly new concepts or go against previous learning"; (What specific things contributed to those changes?) "Seeing the experiments with my own eyes"; (Any general comments...?) "Interesting"; (Any negative feelings...?) "No"; (Any other comments?) "I get frustrated because we are not told anything like in normal classes." The extreme case ...

of this apparent failure to have the experience of successful learning cause a change in conception of what counts as teaching and learning came from a student in Single High School. She was keenly involved throughout, demonstrated a Newtonian perspective on all questions, and scored 100% on the grading test. On the reaction sheet she was very positive, and in an informed way. But there were negative feelings: "We could have had more notes". What purpose these notes might have served is quite unclear; the comment reflects a view that "real" teaching involves giving notes.

Year 11

The mid year examination: The examination given at Senior High School was of a very familiar form. Examples of mechanics questions on the exam are: given pulling force and frictional force acting on a trolley of given mass, calculate resultant force and, after a given time, acceleration and velocity; given a body held by a string on a smooth inclined plane, resolve the weight force and calculate the magnitude of the force holding the body. The exam was a very typical example of traditional testing of the ability to use formulas to solve standard problems. Thus the exam was of considerably different orientation to the focus of the year 10 instruction.

The purpose in considering these examination scores was to determine if there was any effect on year 11 performance (as opposed to year 11 learning) from the year 10 instruction. The rankings of the former Junior High School students were significantly higher than the rankings of the remaining 82 year 11 students ($p < 0.0001$, Kruskal-Wallis test). As already described the exam contained questions on kinematics and light as well as mechanics, and subscores for mechanics questions could not be obtained. Hence it can only be inferred that the Junior High School group performed better in mechanics, although there is no other plausible explanation for the difference between the two groups. This suggestion of clear cognitive advantage to the

Junior High School group is particularly interesting given the nature of the examination.

The conceptual test: Results of this test are considered very briefly here. In essence, most of the Junior High School students used the same conceptions as they had on the year 10 conceptual test or DOEs for situations which paralleled those of year 10. This was particularly evident for falling bodies, an area where the year 10 data suggested substantial conceptual exchange at that time. There is the strong suggestion then that conceptual exchange achieved in year 10 was quite stable for many students. The level of understanding in these areas for the Junior High School students as a group was higher than that of the other 82 year 11 students.

The interviews: Although both performance differences and differences in understanding were found for the former Junior High School students, the perceptions of these students were of greater interest. As previously described, the interviews were conducted in groups and focussed on three areas - recollections of the year 10 instruction; perceptions of differences between this instruction and other year 10 science classes; views of the value or otherwise of the year 10 instruction to their year 11 physics. The interviews were conducted at Senior High Schol and Single High School after the mid-year examination results had been released, and about 10 calendar months after the completion of the year 10 instruction.

The three areas on which the interviews focussed are now considered. Where quotes are given, these are from Senior High School students unless otherwise indicated.

(a) Recollections of year 10: The name of the research assistant who conducted the year 10 classes was recalled by all but 2 of the 24 Senior High School students from whom these data were obtained, and 4 of the 6 Single High School students. In itself, this is interesting when the brevity of the experience and the time since the experience are considered. When particular events from the teaching were recalled, commonly standing on tables or dropping objects, these were recalled with quite reasonable accuracy and sense of purpose. In one case, a student recalled a demonstration of an object placed on a sheet of plastic food wrap held at its ends in order to show distortion in the food wrap. This did not take place; it is in fact a sequence in a T.V. commercial. However the description was most appropriately congruent with a series of observations which were discussed in trying to create an acceptance of distortion in surfaces with objects on them (thus providing an explanation for normal reaction forces). Hence, by having reconstructed the memory to include the food wrap, the student was showing substantial recollection of this segment of the year 10 experience, and understanding of its purpose.

Throughout the interview transcripts there is quite strong evidence that students had accurate memories of the content of the course.

(b) Perceptions of the year 10 teaching approach: There was widespread recognition of the central importance to the year 10 approach of student input, discussion and thought, and some recognition of the purpose of this approach. Such comments included:

> Instead of actually teaching the work he sort of had us in a discussion group and we sat around and discussed the topics to see if the class could find the answer.
>
> When he asked a question and when you gave an answer he would say "Yes, its probably right, but why do you think that?" It was a bit hard to work out what he was really after. He wouldn't tell us what was right or what was wrong. We just had to figure it out for outselves.
>
> We had to think for once, and he wouldn't tell us the answers straight out, but he would hint at it and if you thought about it enough you would realize you were right or wrong about what he said.
> (Interviewer: But he didn't give you the answer?)
> Well he did, more or less. He gave you a clue and then you would have to work out the rest yourself.
>
> The idea of having everyone involved [meant] you were able to get other people's opinior and use them, instead of just doing straight theory about what should happen and what does happen and what doesn't happen. You got a reason why it should happen and shouldn't happen.

> I think we learned a bit more because we actually had to think about it, what we were doing, instead of having the answer there before us. We had to work it out.
>
> Mr S.....sort of led us up to how [the theories] were formed so we could know the basis behind them. (This student contrasted this with his perception of the usual year 10 approach: "They taught us the theories without any background to them".)
>
> I think it helped us see what - er - whether things are right or not for ourselves. Our teachers actually usually expect us to actually believe them, whether they are true or not. (Single High School)

Some more general comments about the year 10 experience were consistent with the views expressed above

> Mr S...., he kind of brought everyone in so that you got the quiet people and the big mouth who sits there and craps on about a whole lot of rubbish.
>
> The [usual] teachers, they don't like to ask kids who won't know because it slows up the class and all that, and it wasn't like that with Mr S..... He would sort of ask everyone if someone had something to say and if it is wasn't right he would sort of try to go into why it wasn't right instead of just saying it was wrong.
>
> Mr S...... certainly made sure everyone knew what he was doing, like if there were any queries he just kept going over it until they understood it. He seemed to have so much patience with us. He didn't have any favourites in the class like most teachers have got a favourite boy or girl who sits there and smiles and answers all their questions.

Of course not all comments were positive. Critical views almost always involved a perception of lack of specificity in the approach.

> The problem was he never gave us an answer. He always told us the question but he never told us if we were wrong or not. He never gave us an answer, and you would expect him to give you an answer.
> (Interviewer: Why?)
> To see if we were wrong or not to correct ourselves.
>
> He didn't normally tell us if we were right or not - we would do something and would give him answers and he would just sort of go "mayby, you could be right". He wouldn't tell us if we were on the right track.
>
> He didn't really tell us any actual information. We had to figure it out for ourselves and we didn't know if we were right or wrong.
>
> It takes too much time to work. We have been brought up to sort of working quite quickly, and although we don't know what we are learning we still get through all right.

...

As well as hinting at profound issues about the general nature of schooling and learning, this last comment raises an aspect of the year 10 instruction which was widely commented on - the pace of the instruction in terms of content covered. The slower pace was sometimes seen as a negative, as in the preceding quote, and more often as positive, as implied in some earlier quotes.

Explicit comparisons between the research-oriented year 10 instruction and other year 10 science classes were sometimes most insightful. A few examples are now given. The first three of these interview extracts are about comparisons between the usual year 10 approach to laboratory work and the DOE approach used in mechanics.

> Student 1: Instead of us all doing our separate little experiments we did one major one so that we were all thinking about the same thing and getting the same results.
> Interviewer: You got the same results?
> Student 1: Well, not the same results, but we all had the same experiment to get our results from.
> Student 2: Yes it was good because the group was all involved and it wasn't as if we were sort of all scattered over the room [with] some people down the back and not doing much and all the other people up the front would be sort of half listening or whatever. [With Mr S....] everybody was getting really involved and some of the discussions were pretty far fetched. But it was good because everybody would just sort of throw their opinion in and then when you heard what other people thought it would sort of....you know.
> Student 3: It was good because you got a lot of feedback from the others, you could think about your ideas and you could use their ideas as well.
>
> [With usual year 10 laboratory work] we didn't have to predict anything first. We did the prac. and we found out what it did - we didn't predict it, that's what's different.
>
> [With usual year 10 laboratory work] we knew what was going to happen if we did the experiment. We knew what the experiment would bring out so we would know the results before we actually did it, rather than with Mr S.....we didn't know what was going to happen so we had to predict, which really made you think, or try to think, or guess. (Single High School)
>
> The real difference was that Mr S....didn't give us any straight facts, he just gave us a question. We didn't get an answer where [with] other teachers we would have the facts, we didn't have to answer any questions, they would just tell us what would happen then they would give us a question. They would give us the information we would need to solve those questions, where Mr S....asked the question first and we had to struggle with it in our own way and we had to figure out what happened in our minds, what was going to happen.

Some saw the position described in the last quote as indication that the usual year 10 teaching approach was better.

Two Single High School students explicitly described their beliefs that the alternative approach gave them helpful memory referents: "things that could trigger off our memory"; "it's more visual you know". One of these students also said "...but one thing that got me was we didn't take any notes". This was the same student whose year 10 written reactions about the absence of notes have already been described.

Preference for either the usual year 10 approach or that used for mechanics was in line with the perceptions the students had of the two approaches, with one qualifier. Often those who favoured the mechanics approach also referred to the pressure to cover content in their year 11 physics course. This perception of time pressure then sometimes led them to argue that both approaches were needed - one to cover the work, the other to understand some of it. The inconsistencies which this argument contains were not explored with the students.

(c) Did the year 10 experience help with year 11 physics? This was the question of greatest interest - could the students see the links seen by those conducting the research, given that the students had had no prompts about or assistance with these links? As would be expected, given the context of the study, none of the former Junior High School students gave any indication of any awareness of the year 11 achievement advantage of the group. Of course this is not at all surprising. Achievement scores were then unlikely to have been a significant issue in the responses to the general question of advantage or otherwise from the year 10 experience. Only one Junior High School student made any explicit reference to achievement scores in this section of the interview. None of the Single High School students made such reference.

Of the 24 former Junior High School students whose responses to this broad question are available: 6 answered "yes" in a generally unqualified way; 9 saw some value, giving responses such as "a bit", "a little", "sometimes"; 3 thought it had probably made no difference; 5 were clearly negative in their views.

The 6 responses interpreted as being positive in a generally unqualified way were:

> I think he gave us the sort of basis of forces and all that, what forces were and how they were acting on anything, which we were able to build on this year.
>
> This year in mechanics we kind of knew it but put it into more depth....Had an exchange of ideas last year. It gave you a better insight into ways of looking at the problem.
>
> This year we didn't have to have anything proved to us because we already knew most of it and we just went into more depth which made it a bit easier because you just didn't have to try to figure out why it did it.
>
> It did give you a general understanding of a lot of aspects last year so this year you came in and understood most of what [year 11 physics teacher] was trying to convey. And that was a help.
>
> It did help me, but if there was more theory applied in year 10 it would be better. We were given a better insight, so understanding it better in, like, in year 10. That's given you a fairly rough outline of what was going to happen and then in year 11 just telling you why it was happening.
>
> I think it did [help], because we understood it before we actually did it [in year 11]. So you had already done it before - understanding with mechanics, not the equations or anything - we understood it. So you understood it without the mathematics and the definitions and you had a general idea of what was going on.

This last student had formed views nearer to the issues underlying the design of the year 10 instruction than had any other student.

The comments of the 9 students who were more ambivalent, but still somewhat positive, were varied. Some referred to help only with specific content, such as force diagrams ("...whereas some of the kids who hadn't seen [force diagrams] before were sort of looking at this diagram saying 'UGH! what's wrong here?'"), air resistance ("...being able to pick up things that say the teacher had forgotten like a little bit of air resistance in a certain prac."),practical work with falling objects, forces on objects ("...the one I can remember that was hard for people [from other schools] this year to understand was that sort

...

of no force was acting on a ball after it had been hit by, say it was hit by a golf club"). One was reserved in his views of usefulness of year 10 because of the greater mathematical content in year 11 physics: "We had a good knowledge of what was going to happen, but when it actually came down to the mathematics part of it, it was a bit difficult". The remaining students were more vague in their reasons, for example "I was surprised, it did help a bit", and "It helped a bit, but not as much as I thought it would because I didn't do that well with forces this year" (this last comment is the one interpreted as referring to achievement scores).

The 3 students who saw year 10 as essentially of no help expressed views such as "if we had been taught normally we would have got the same thing, maybe even more".

However there was no such ambivalence with the 5 students judged to be negative. All pointed to what they saw as specific deficiences in the year 10 experience, with some seeing that experience as a clear disadvantage.

> There was no advantage .... We didn't get the, like, the equations and how to work it out so when it came to the actual working out it was the same as everyone else.
>
> I didn't think we had any particular advantage having Mr S.... I think we would have been better off without him actually, that's my opinion.
>
> ...a lot of the things we did with Mr S.... you had to take friction and air pressure into account whereas this year you forget all about that, and we didn't do any problems last year and we didn't do anything like that at all.
>
> No help. I don't think he gave us the right answers, he just said what are your views, not really right and not really wrong...What we did last year was pretty limited anyway. All we did was just work out accelerations of falling objects and that sort of thing. A pretty small area that we covered.
>
> Physics this year consists of learning and memorizing formulae. This holds true for the force unit. Many other people, from other schools besides the one I attended last year, knew many of the formulae. I was somewhat left in the dark at the start of the unit. I feel it is necessary to study the theory and then do the practical side.

...

Among the 6 Single High School students, 3 clearly believed the year 10 instruction was helpful to their year 11 physics learning, and 3 saw year 10 as not of any help. All the latter 3 explained their perception of no value in terms of year 11 content having no real connection to the year 10 work: "It's mainly new stuff this year". This surprising view reflected their belief that year 11 physics was essentially work with formulae.

Discussion

There is evidence of conceptual exchange having been achieved with at least some students in this study, as shown by performance on the conceptual tests in both year 10 and year 11. However, just as with the previous work with graduates on which this study draws (Champagne, Gunstone & Klopfer, 1985), it is argued that more powerful evidence of conceptual exchange is to be found in the metacognitive comments of some students. For example, the student who commented on the learning difficulties of others with forces on a ball in flight, those who talked of having to think through to their own answers "for once", those who described using other students' ideas, are all giving some indication of having accepted and understood an idea sufficiently well as to be able to describe something of how they came to ambrace the idea. Of course it is not argued that any such metacognitive insight is a guarantee of substantial understanding. What is being argued is that metacognitive insights, in general, can be a better indicator than test performance of conceptual exchange. This is so because there is at least some greater likelihood of internal fruitfulness being seen if the conceptual exchange is accompanied by increased metacognitive awareness. The presence of such awareness indicates that genuine exchange, rather than rote acquisition of compartmentalized formal knowledge without abandoning conflicting spontaneous knowledge (Pines & West, 1988), has been achieved.

To illustrate this, consider two year 11 comments given above about air resistance in physics. One student described being able to bring into their work things that "the teacher had forgotten" such as air resistance, the other placed air resistance and friction in the bag of things "you forget all about". One reasonable interpretation is that the first student is able to and concerned to relate what is being learned in physics to existing ideas and the world around them, while the second student is concerned with considering formal physics in isolation.

This second student is also giving a perception of physics which was quite common among these students, and many others at school or in teacher training courses with whom research has been undertaken. That perception, that physics is essentially mathematical and abstract and unrelated to the day-by-day world, has major implications for the nature and style of physics curriculum and teaching. This significant issue has been discussed elsewhere from a variety of perspectives (e.g. Driver et al., 1985; Gunstone, 1975; Osborne & Freyberg, 1985).

Perceptions of the nature of school physics offer the most likely explanation of the similarity, in terms of extent of year 10 conceptual exchange, of the group electing to study year 11 physics and the group not studying year 11 physics. In the extreme case, 2 Single High School students claimed the year 10 instruction had no conceptual connections to year 11 physics. A number of students indicated views of this form, if not quite as extreme. The views can be summarized as year 11 physics focusses on issues other than understanding concepts; hence, by inference, achieving an understanding of fundamental concepts will not assist with learning year 11 physics. This inference is supported by data from a naturalistic, longitudinal study of conceptual exchange in school physics (De Jong & Gunstone, 1988). In that study, students commonly attributed success in year 11 physics to high intelligence and a good memory - two factors seen as issues beyond the control of the individual.

Conclusion

The study had three purposes: (i) to explore the effect on subsequent performance on related content (external fruitfulness) of any conceptual exchange; (ii) to explore subsequent perceptions of nature, purpose and value (internal fruitfulness) of conceptual exchange oriented instruction; (iii) to explore the utility in usual educational contexts of approaches which had previously been successful with science graduates in a laboratory context.

The data suggest that the approaches used in year 10 had some utility in terms of promoting conceptual exchange, but the effects of the teaching were less dramatic than we achieved with graduates previously; the year 10 instruction has had effect on year 11 mechanics performance, but the year 11 students were generally unaware of this; year 11 perceptions of the value of the year 10 experience were varied. When considered in terms of fruitfulness it appears on the surface that external fruitfulness was achieved. However the failure of many students to see any cognitive advantage to them means that many students did not perceive any external fruitfulness. For some students there was evidence of internal fruitfulness in the metacognitive insights they gained.

Given the change in context and different nature of students from the previous work to the present study, these general patterns were to be expected.

At one level the achievement of at least some conceptual exchange in year 10, and the apparent year 11 congitive advantage promoted by this change, are both heartening and educationally significant outcomes. However the lack of perception of value of year 10 among many of the year 11 students is disturbing (and is reinforced by a number of the written comments about year 10 given by students at that time). The study was planned to allow withholding from students metacognitive prompts such as direct reference to the year 10 experience by year 11 ...

teachers, explicitly teaching in year 10 about the purpose of the experience or the perceptions of the researcher of the value for subsequent learning, etc. That is, any conceptual exchange was made as deliberately uninformed (in a metacognitive sense) as possible. Some students have constructed some of these links for themselves, an impressive and cognitively helpful achievement. However, many have not. It is argued that for these students the cognitive advantage they appear to have midway through year 11 physics will be only ephemeral. If students are unaware of these fundamental aspects of their learning, it is clear they can neither build on and develop these aspects nor use them to enhance their own learning. In this sense the study reinforces the need to explicitly help students understand and control their own learning as a major contributor to developing their own understanding.

This last point is well illustrated by considering again the two sources of knowledge described by Pines and West (1986). Students have much spontaneous knowledge about learning as shown by data in this and other studies. Despite learning being the major proclaimed purpose of our educational structure, and despite there often being conflict between students' spontaneous knowledge and the views of learning underlying classroom experiences, we almost never explicitly address this conflict. Where formal learning about learning has become part of the instructional agenda (e.g. Baird & Mitchell, 1986; Gunstone & Northfield, 1986), the results have been most heartening.

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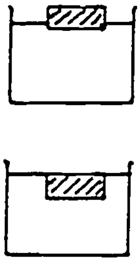
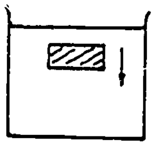
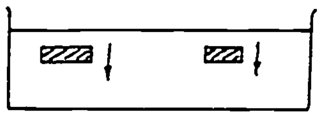
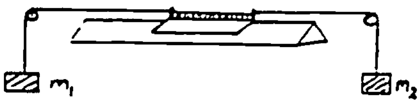
Appendix 1 : Outline of year 10 instruction

TOPIC	CONCEPT	ACTIVITY	QUESTIONS/DISCUSSION/EXAMPLES
Introduction		(1) Brief introduction to the sequence and its objectives - main purpose is to find ways of teaching science which make understanding more likely.	
	1. What is a force? 2. General idea of force as a push or pull. 3. Directionality is important	(2) DOE # 1 1) Book dropped. Does it speed up? Reasons. Why does the book fall down? 2) Book on table Why doesn't book fall down?	
1. Normal Reaction Force	1. Forces act on an object. 2. Forces acting but no motion	Minstrell sequence: (1) Book on table (vote) (2) Book on hand. (3) More books on hand (4) Book on table (vote) (5) Stand on table. (6) Ruler as "model table" (7) Book on spring (1) (8) Book on spring (2) (9) Book on table (vote)	What are the forces acting on the book? What effect does table have? What causes upward force? e.g. Standing on trampoline, diving board, Standing in quicksand
2. Forces (general)	1. Forces act on objects and have causes.	Discussion of forces - contact type - non-contact type. Convention - arrow indicates direction - length indicates size	

3. Floating	1. Forces acting but no motion. 2. Net force is zero	 (1) Wood floating in H_2O (2) Mass increased until just floating	What are forces acting on the block? Link to Minstrell sequence. What is <u>cause</u> of upward force? How does upward force change? What does upward force depend on? Why do steel ships float?
4. Free fall (single ball)	Net force produces change in motion	Drop light & heavy balls separately.	Does the ball get faster? What are the forces acting? Is there a net force? How do we know? Does each ball fall at the same rate? How can we find out?
5 Free fall (DOE#2)(1)	Net force produces a change in motion	A B Two balls, same size, different mass dropped ≃2m. Which mass will reach the floor first?	If so, in what way? Is there a net force? How do we know? Is it the same for A & B? Is the change in motion the same Is the result what was expected from a logical analysis? (Lead into #6.)
6. Free fall (2) (10m)	Net force produces a change in motion	A B Two masses, same size, different mass, dropped ≃10m. Which mass will reach the ground first?	How is this different to #5? Is the net force the same for A and B? Compare with Galileo-Pisa statements in texts. Parachutes Raindrops through skull? (throw H_2O from 10 m also?)
7. Review	1. Net force zero, no motion. 2. Net force, change in motion	Cards, diagrams etc. of real world situations - indicate forces acting. Introduction to friction - if not already covered.	Discussion of particular examples.
8. Reaction (1)			
9. Forces and constant velocity	If net force is zero, no change in motion.	Vacuum cleaner experiment  Forces acting? Net force? (Ask students to vote and then demonstrate the main contenders)	How can the puck be made to move across the table at constant speed? What are the forces acting? A constant force is needed to push a bike at constant speed. Why? Example of car at constant speed of 100kph.
10. Sinking	Net force leads to change in motion.	 Extra mass added to ensure sinking.	What are the forces acting as the block sinks? How do the sizes of the forces compare? Is there a net force? Direction?

11. Sinking (DOE #3)	Net force leads to change in motion	 Masses added to A and B until they just float. The same mass is added to both to ensure sinking.	Which mass will reach the bottom first? Discussion: Forces acting? Net forces? Which is greater? Effect of <u>mass</u>. e.g.(1) Will a VW engine produce the same acceleration in a 10 tonne truck as it did in a car? e.g.(2) Small stone/large stone comparison?
12. Analysis of Motion	Semi-quantitative analysis of motion and change in motion	Dot profile analysis Examples and analysis of 1. constant speed 2. increasing speed 3. decreasing speed 4. mixture of speeds (1–4: high/low)	Plot a 'graph' of speed (motion) against time.
13. Net force and change in motion	Net force leads to change in motion. No net force, no change in motion. <u>Direction</u> of net force for motion inc. and dec.	Air track experiments  Motion with $m_1 = m_2$ $m_1 > m_2$	What are forces acting <u>on</u> the the glider? How can we achieve (1) constant motion? (2) increase in motion? (3) decrease in motion? Examples: Cars Bikes Spacecraft in 'deep' space.
14. General Review	If net force is zero, <u>no change</u> in motion. A net force means a change in motion. Direction of net force and change in motion.	Analysis of diagrams, beach scene, etc.	Discussion of particular examples.
15. Final DOE		Chosen from: (1) Ball thrown in the air (2) Ball rolling on horiz. table. (3) Golf ball in mid-flight. (4) Equal masses at different heights (after Gunstone & White).	Discussion as it arises to to reinforce view that net force needed for change in motion.
16. Reaction (2)			