Improving understanding in physics: An effective teaching procedure
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Abstract
The bell rang for recess. No-one moved. Everyone in the class wanted the question resolved. The discussion continued ... Sounds like a typical physics lesson? Not really. Yet it happened with different teachers, classes and schools while using a Conceptual Understanding Procedure (CUP) described in this paper. This teaching procedure is designed to improve students’ understanding of difficult concepts in senior secondary physics, but with equal applicability in other sciences and at other levels. CUPS are based on a constructivist view of learning, target individual students’ ideas and use cooperative learning. Teachers will find them a worthwhile addition to their repertoire.

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Introduction
Physics has an image problem (see for example Webster, 1998, p. 11). The popular view is that it is somewhat abstruse and theoretical and a subject for students who are highly intelligent, mathematically inclined and male. In recent years there have been various attempts to make physics accessible to a wider range of students. For example, authors of physics textbooks now tend to include examples of physics situations to which female students can relate. In Victoria and Western Australia, designers of the physics curriculum adopted a contextual approach in an attempt to bridge the gap between the theoretical and the real world.

These changes have not however led to more students studying physics. In Victoria, for instance, the proportion of Year 7 students studying physics five years later (i.e., at Year 12 level) has remained constant over the last twenty years, at around 4% for girls and 12% for boys (O’Keeffe, 1998). It would seem that the perception that physics is hard continues to deter many students from choosing to study it.

We believe that central to physics’ image problem is how it is taught. While the changes mentioned above are laudable, they are not sufficient. Physics teaching needs to move beyond handing out notes, solving numerical exercises and doing demonstrations and experiments. It needs to address issues raised by research in the last two decades
about how students learn science and, in particular, physics. Firstly, it needs to embrace teaching strategies which have a constructivist perspective, that recognise that the way students make sense of what happens in a lesson is by attempting to link it to their existing individual frameworks of ideas and knowledge. Inadequate linking usually results in learning that is basically isolated bits of information; linking to incorrect ideas often leads to misconceptions. Both of these outcomes are likely to impede further physics learning (among many examples showing this to be so are Glynn & Duit, 1995; Gunstone, 1990; Osborne & Freyberg, 1985).

Secondly, learning can improve when students become more aware of how they learn. When they understand more about how they learn, students can use the insights gained to help them learn more effectively in the future (Baird & Northfield, 1992). In brief, this involves greater knowledge of learning and their own approaches to learning, increased awareness of the nature of learning tasks they are given and their own progress through these tasks, leading to greater control by students over their own learning.

Teachers cannot mandate any of these things. They cannot ensure that students will make correct links or actively reflect on how they learn. However, there are teaching strategies which will make these outcomes more likely. A key idea behind strategies that encourage good linking is the importance of getting students to think about their existing ideas and to challenge these ideas if necessary. This encourages students to reconsider faulty ideas, reorganise others and incorporate new ones into their mental framework in ways that result in better understanding. Being able to see how their own thinking has shifted can also encourage in students greater awareness of their learning and reflection on the processes by which they learn.

Outline of this paper

In this article we discuss the use of CUPs (Conceptual Understanding Procedures) in helping students’ learning of physics in Year 11 mechanics. The CUPs approach, which two of us originally devised for use in first year physics at Monash University (and which was trialled there in 1996) (Mills, McKittrick, Mulhall, & Feteris, 1999), involves cooperative learning and is based on the constructivist ideas discussed above. CUPs are designed to appeal to students of both sexes and can be easily incorporated into a normal classroom.

A CUP involves a qualitative exercise which students are asked:
- to think of one idea first; then
- to discuss their ideas; and subsequently
- to discuss and share their ideas with others.

In the teams of three, students are asked to reach a consensus. Responses are recorded in the form of diagrams to enable semi-quantitative ideas to be easily conveyed. It is each team’s response that is discussed in the whole class mode, with the teacher acting as a facilitator as the students work towards a single consensus. We explored the use of this strategy in schools during a research project in 1997, a brief outline of which is given later. The main purpose of this paper is to provide sufficient information to enable interested teachers to decide whether they wish to trial the procedure for themselves in their own classrooms. We therefore focus on how to use a CUP and the responses from teachers and students who trialled the procedure. Typically the reactions from both groups were very positive.

CUPs in theory

A typical CUP

An example of a CUP exercise is shown in Figure 1. Each CUP exercise contains a few questions set in a ‘real-world’ context that it is intended students can easily see or imagine. The questions are designed to encourage students to think about underlying concepts. These contrast with the questions more commonly used in physics classes where reaching the correct answer depends primarily on recognising the appropriate formula in which to substitute, without students necessarily achieving any real understanding about the relevant physics ideas. The information and questions therefore need to be framed in such a way that their solution will require not merely this algorithmic approach, but genuine inferences about basic concepts.

As mentioned earlier, responses are recorded in a diagrammatic form so they can be communicated easily to others. Diagrams also enable semi-quantitative ideas to be expressed because even though the exercises are qualitative they often involve consideration of the relative sizes of different quantities, e.g., forces. It is important to establish rules to be followed when drawing diagrams so that they can be easily interpreted with minimal verbal explanation. Hence as the example shown in Figure 1 involves thinking about forces, a box has been included which tells students how to represent forces.

Outline of a session

Before the very first exercise, the purpose and cooperative nature of the sessions is explained to the students. They are told that the intention of these sessions is to improve their understanding of physics by providing them with the opportunity to become aware of and develop their ideas, and in particular to correct any which may be wrong.

In addition, students are allocated to teams in which they will discuss the exercises. Based on research by Heller and Hollabaugh (1992) into the optimal structure of cooperative learning groups, each team contains three (or four if necessary; never two and never more than four) students of mixed ability, with female students being grouped with at least one other female.

The teacher then introduces the exercise and gives each
Ex 3  Hitting a golf ball

1 The diagram shows a golf ball sitting on the ground before Leigh hits it. On the diagram mark in and label two forces which are equal in magnitude and opposite in direction in accordance with Newton’s Third Law of motion.

Represent forces
- using directed lines
- using the same scale for all forces within each diagram
- with as large a scale as possible to highlight the relative magnitudes
- with the tail of each directed line at the point where the force acts
- offsetting collinear forces to clarify the points where the forces act, and
- labelling forces using a convention such that the force exerted on the Ball (B) by the Ground (G) would be labelled $F_{BG}$.

2 Before Leigh hits the ball he thinks: “According to Newton’s Third Law the clubhead will exert a force on the ball and the ball will exert an equal and opposite force on the clubhead. Therefore the net force is zero, and the ball should not move. But I know it will!”

The diagram below shows the clubhead in contact with the ball as the clubhead swings through. Mark in and label all the forces acting on the ball.

Use the conventions in the box above.

3 [If time permits] Can you see what is wrong with Leigh’s thinking (above)?

Figure 1. An example of a CUP exercise
student a copy of it on an A4 sheet. At first the students work alone on their own. This gives them the chance to get in touch with their own ideas before listening to what other students think and prepares them for active participation in the discussion, which is to follow. It also largely removes the possibility when students later work in a team, of not engaging at all with the group task—often a problem with group work.

After about 5 to 7 minutes working alone, the students spend about 20 minutes discussing the exercise in their teams, with each student sharing his or her ideas as well as listening to those of others. The goal of this discussion is to achieve consensus about the answer, which the team records on an enlarged A3 copy of the exercise.

For the final stage of a CUP, which usually takes about half an hour, each team’s response is attached to the wall or a board at the front of the classroom using blu-tac. The teacher then invites the students to sit close to the front of the room and to scrutinise the responses of all teams. Their task now is to work towards a whole class consensus on the answers. The teacher points out the similarities and differences between the teams’ responses but offers no judgment about their accuracy. Individual teams are asked to explain and defend their responses. As the discussion proceeds some teams may decide to modify their answer. One characteristic of the whole class discussion is that much of the interaction is student-student, rather than student-teacher. When consensus is reached, the teacher marks the agreed response on a new A3 sheet, headed ‘Class consensus’. Closure of the session is achieved as the teacher summarises the key arguments which have been put forward in its favour and assures the class that these arguments will be followed up in the next lesson.

The purpose of consensus

The purpose of seeking consensus, initially in the team and then in the whole class discussion, is to stimulate active thinking and learning by the students. To achieve consensus involves carefully explaining one’s ideas and comparing them to others’. This can lead to an awareness of ideas that are wrong or need to be modified, and paves the way for development of an improved understanding of the concepts involved in the exercise and for better learning than would otherwise occur in subsequent classes.

Sometimes it is not possible to achieve consensus in the allocated time. In this situation closure can be achieved by summarising the arguments for and against the most popular response (the ‘Majority response’) and, as with a consensus response, telling students that this will be discussed during the next lesson. In the follow up to the session the uncertainty that has been created by the discussion will tend to ensure that the students are more receptive to the teaching which occurs than would have otherwise been the case.

The teacher as facilitator

The teacher’s role in these sessions is different from their normal one. It defeats the purpose of the exercise if the teacher offers judgment about the accuracy of the students’ responses or leads them to the right answer. Rather the teacher’s role is to facilitate the whole class discussion by keeping track of similarities and differences between the various teams’ responses, by asking individuals to defend their team’s responses and by asking whether any students wish to change their team’s response in view of the arguments which have been presented. This encourages active involvement by the students and leads to better learning than occurs when their role is to merely sit and listen.

The need for trust

For students to benefit from this activity they need to be honest about their ideas. Yet saying what one really thinks involves the risk of being ridiculed if one is wrong. It is important therefore to develop an atmosphere of trust between students and between students and the teacher. The teacher can foster this by encouraging students to respect each other’s ideas and by modelling this behaviour (Baird & Northfield, 1992).

Grouping students into small teams for the initial discussion also helps shy students to feel confident about airing their ideas as this is much less daunting than talking in front of the whole class. In addition, presenting the team’s response rather than the individual’s in the whole class discussion further generates confidence and avoids the possibility of embarrassment.

CUPs in practice

The research

This has been discussed in detail elsewhere (Gunstone, McKittrick, & Mulhall, 1998). Briefly, the research involved two Year 11 physics classes whose teachers worked with us to design the three exercises used in the trial. One teacher taught a class of 16 in a non-government girls’ school while the other taught a class that had 17 boys and 2 girls in a government co-educational school. One of us was present for each of the lessons during which the strategy was used. Two weeks after the trial the teachers were interviewed separately about their experiences of using CUPs, as were about half the students in groups of three that were not the same as their CUP teams. There were also eight other teachers who were involved to a much lesser extent in the project. They attended an information session during which the strategy was explained and were given copies of the developed exercises for use with their classes. Post-trial feedback from these teachers about their experiences of using CUPs was obtained via a written questionnaire and at a discussion night that was also attended by the other two teachers. All teachers made their own judgments about when to use the exercises in their teaching sequence.
Teacher and student reactions to CUPs

The overall response from both teachers and students was very positive. In particular, the vast majority of students thought the CUP sessions were helpful to their learning. Some aspects of students' and teachers' reactions follow.

It was different

While some aspects, eg drawing diagrams and discussing, were familiar, students and teachers were struck by differences between the CUPs and more typical teaching that emerged as they experienced them. Often teachers tend to use the ideas of a few bright students in developing a correct understanding of a concept. By contrast, CUPs elicited the views of a much larger number of students.

T: The thing I felt was so different about this was ... that you actually got to hear what the kids were thinking whereas in a normal class discussion [you leap on] the first person that [says] something right ... and you tend to ignore anything they come up with that's not quite right.

This wider involvement brought the otherwise unknown views of many students into the open.

T: I reckon you get a really good insight into what they are thinking - that's what I really liked about it, and all sorts of kids popping up that don't often pop up in a class.

Students valued having more class time than usual to explore their ideas about a concept.

S: Normally when we get asked [something] most people don't think about it. They just say 'we don't know' and you just get told [whereas in CUP sessions] you've got time to think [about what you think].

Having to reach consensus in the teams of three and later support this in the whole class discussion effectively coerced more students into participating than was normal.

S: If we were just one big group then I'm sure some people just wouldn't say anything. With the [teams of three] you had to say something.

As a consequence, many students found they were thinking more deeply.

S: This is the hardest thinking I've done all year.

The development of a consensus in the teams of three also resulted in students feeling more confident than usual to speak in the whole class discussion.

S: When you were in [the whole class mode] it's not intimidating because it's not just you because [there were three of us] ... it's a combined opinion [on the board].

T: The second CUP was easier because they ... knew there wasn't going to be that embarrassing [feeling of] I'm going to be put on the spot, I'm going to be laughed at because I really don't know what I'm doing.

More effective learning

As mentioned above, the working alone and in threes enabled the students to get in touch with what they believed about the concepts addressed by a CUP and to modify their ideas when these did not make sense. Furthermore, the articulating of their ideas in the teams of three and whole class discussion was valued as an important means of improving understanding.

T: It helps ... [students] clarify their ideas. Once you start trying to say something you realise whether you know it or not.

S: Everyone usually got their say about what they thought was right and then we could question each other and we had to justify it ourselves ... which sort of meant you had to understand it a bit better to be able to answer questions people asked you.

The teachers attested to the improved understanding they felt students achieved.

T: It's managed to get the idea across too a lot better than anything else I've ever tried ... They still have problems — nothing's perfect — but they seem to have a better understanding of the things we've talked about [in the CUP sessions] than [students have in] other years where I've tried different approaches.

T: They got a lot out of discussing the different concepts and they seemed to have a better understanding of [them] afterwards too.

Awareness of how they were learning

Our experience is that most students rarely, if ever, consider how they learn. However, during the CUP sessions, students were aware not only that they were learning, but also how they were learning. The majority of the student quotes above attest to this. Two others:

S: When students teach each other, you get more out of it because you're ... on the same level.

S: It ... really starts you thinking about other things ... so you want to know more as well.

Some students were also aware they were reflecting more deeply than usual.

S: Yeah, you had to actually think in class (laughter) ... you had to do a lot of thinking to do it.

Both students and teachers saw value in the cooperative nature of the learning.

S: Within your [team of three] you've come up with some ideas but they might not be right ... [the whole class discussion] gives you a broader range of ideas.

T: The idea of the consensus is: I'm not telling you the good news ... The good news is going to come back the other way [from the students] ... and that's much better learning.

S: If I don't understand something, I find it easier to understand it with a friend [explaining] ... If [I] don't understand I feel dumb with a teacher.

The knowledge of how they were learning during the CUP sessions may help students to realise that they can take control of their learning in ways that lead to more effective learning.

It was enjoyable

Both the students and teachers indicated that they enjoyed the CUP sessions despite their being more challenging than other teaching modes.

T: Delighted, absolutely delighted ... at recess time they were still going, no one moved ... I was delighted by all the different heads popping up. ... In the groups of three ... they were really discussing things.
T: Seeing them get that passionate about a discussion in physics was good.
T: [The students] didn’t want to leave until they got the right answer.

**Time**
The teachers found the CUP sessions took about an hour which was considerably longer than the original projected 40 minutes. Our initial perception of this as a problem changed to recognising it as necessary for such a teaching procedure.

T: When it does go well, it’s time well spent. …[Even when it doesn’t go well] you build it up from there, you never lose on it.
S: If longer … I would have got bored … any shorter, people would not have been able to get their arguments out, so I think it was about right.

**Negative reactions**
Only one student was clearly negative in his reaction. This student felt that the bringing out of different ideas was confusing, that being given the right answer would be less confusing.
S: After a while of just continuing arguing over exactly the same things I just don’t even care any more…after the first ten minutes all these arguments have been said, you might as well just give us the answer once you’ve been all over it again and again.

This student’s concerns did not arise from any reluctance to enter into debate – he was confident and articulate. It may be that his reaction to the CUP approach had links with the views he had about learning and the roles teachers should play in this.

The only other negative student reaction was expressed by two individuals. It was that there might be contexts where “you might not understand” the views expressed by another student. However neither student indicated that they had actually had this problem. Rather they were indicating that this might be a possibility at another time.

The teachers expressed some concerns (as described next), but had no substantive negative reactions. This is not surprising as they had volunteered to work on developing the exercises and trialing them.

**Challenges for teachers**
From the teacher’s point of view, launching an effective interpretive discussion based on the range of views expressed on the A3 sheets just after they had just been attached to the front wall was very challenging.

T: [A difficulty] is thinking on your feet when you put [the A3 sheets] all up, “Goodness, what am I going to do with all that?”

This difficulty can be minimised if teachers:
- think carefully before the session about likely incorrect responses and
- observe the responses being recorded by groups during their discussions in the teams of three.

Some teachers also found it difficult to maintain the non-committal facilitating role during the interpretive discussion rather than moving into a more typical role of guiding the discussion or giving them a correct answer.

T: In the last [CUP I became] very much more aware that [normally] you’re forcing your agenda on the kids, so you’ve got to try to avoid that. That’s the hardest thing. It was the least successful one by far … I [thought I knew what they knew—but of course they didn’t know it.
T: [One of the challenges was] not telling them the right answer!

**A frequently asked question**
Teachers who have not used CUPS sometimes express concern that the class consensus may be completely at odds with correct physics. This has never been our experience. In part this is probably because the design of the exercises takes appropriate account of the physics knowledge and abilities of students at the Year 11 level. Additionally, the structure of CUPS ensures a high level of student involvement, both in terms of numbers and intellectual engagement. Consequently incorrect ideas are more likely to be challenged than in more typical class discussions which are often dominated by the views of one or two students. However, sometimes the class consensus has not been completely right. To ensure that students are made aware of the correct physics response, the teachers concerned provided appropriate follow-up discussion and/or learning activities. On those occasions when class consensus was not completely right, the teachers were clear that the thinking of students immediately following the CUP was always more advanced than would have been the case if the CUP had not been used.

**The significance of students’ awareness of their own learning**
In the early part of this paper we indicated that student learning can improve when students become more aware of how they learn. This was not a focus of the teachers’ uses of the CUPS that we have described above: their concerns were very much with better conceptual understanding of physics concepts. Even so there were interesting indications among some of the student responses to our questions that their CUP experiences had resulted in some of the students thinking more about their own learning. Logically this is not surprising as the CUP procedure does attempt to have students reflect on and reconsider their thinking about physics concepts. Given this, it is also not surprising that we believe that having students be more aware of how and why they think and reflect will itself lead to better understanding of physics, whether through use of CUPS or any other approach concerned with understanding. Approaches that focus on students being genuinely engaged with thinking about the ideas they are learning offer great opportunities for teachers to develop students’ knowledge, awareness and control of their learning.
Conclusion

Many physics teachers will recall the statement "I teach physics" in casual conversation giving rise to one of two polarised responses such as "Oh! I dropped that as soon as I could" or "That was the most stimulating subject at school." Unfortunately, the frequency of the first response is much higher than that of the second.

Many students do not find traditional methods of teaching help their understanding of physics. Even successful students such as physics graduates may have understandings about physics ideas that are at best inadequate and at worst erroneous. By contrast, CUPs offer an effective way of improving learning and understanding which students and teachers alike find both valuable and enjoyable.

Note


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References


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