A cooperative learning strategy has been developed to help first-year tertiary students overcome common misconceptions in mechanics. In this Conceptual Understanding Programme (CUP), students work on exercises alone, then in threes and finally discuss their views in the whole class. This process encourages students to actively think about and modify their views and it results in a high level of participation and satisfaction. The strategy can be implemented without major changes to a teaching programme.

Our experience, widely shared by others, is that good lectures do not guarantee a good understanding of key concepts in introductory physics nor do standard textbook problems necessarily develop conceptual understanding [1]. Strategies that have been successful generally involve students thinking actively, for example in the workshop physics approach, and may require a total restructuring of teaching [2].

Our strategy, the Conceptual Understanding Programme (CUP), makes use of cooperative learning, can complement existing teaching programmes (lectures, laboratory) and requires no expensive equipment. We have found it to be effective with as few as four hours of class time per semester.

Getting a handle on CUP

For the last three years, our first-year students have had a weekly one-hour small class in the four weeks of introductory mechanics. These CUP classes have 16–20 students, small enough for students and staff to get to know each other. A ‘facilitator’, a postgraduate student who has undergone a short training programme, leads each CUP class. To optimize cooperative learning, students are allocated into teams comprising three (or occasionally four) students of mixed ability; female students were usually placed with at least one other female [3].

The sessions explore students’ understanding of particular concepts in real-life situations. With a cooperative learning approach we have maximized the opportunity for students to work through their misunderstandings. Students first think about the situation on their own, then work as a team. Each team commits their response to a diagram and then the whole class discusses these diagrams, with the facilitator guiding them towards consensus.

Typical exercises

The exercises are largely qualitative in order to focus on concepts, and are based on selected real-life situations that are prone to misconceptions. Diagrams are used extensively in order to allow students to represent the relative sizes of different physical quantities without calculations and to allow ready communication in the team and whole-class discussions. A typical 50 minute CUP session consists of two exercises. The following is a brief description of the very first exercise.

The facilitator asks students to think about a golf ball and a foam ball of the same size dropped from the same height above the ground, and to predict which will hit the ground first. After making their prediction, they observe what
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happens in a demonstration. Each student is then given an A4 worksheet showing the tasks and diagrams on which to show their answers. The first task is:

A golf ball and a lighter foam ball are dropped from the same height. Draw arrows showing individual forces acting on each ball (a) early in the fall and (b) later.

For the exercises and discussion to proceed efficiently clear conventions are essential, e.g. each force is to be represented by a directed line, using a large scale to highlight the relative magnitudes of the different forces, with the tail of each directed line at the point where the force acts, and using a convention $F_{AB}$ to label the force exerted on object A by object B. Different colours help distinguish forces.

After the students have worked alone on the exercise on their A4 sheet, they discuss it in their team. When the team has reached an agreed answer they transfer it to a large A3 copy of the diagrams. These A3 sheets are then attached to the front board and all the students gather around to view them. Figure 1 shows a possible correct response while figure 2 includes some common misconceptions.

The facilitator then guides discussion in the whole group. Students are encouraged to look for similarities and differences in responses; some are asked to justify their solutions and others to support or disagree using reasoned arguments. Quite high-level teaching abilities are needed to guide such a discussion towards consensus without simply giving away the correct answer.

The four sessions for the trial in introductory mechanics addressed free-body force diagrams and Newton’s laws, circular motion, conservation of energy and conservation of momentum. Other CUP sessions used space-time diagrams in special relativity and $P-V$ diagrams in thermodynamics. Exercises in kinematics and dynamics have been trialled at secondary school level. Some CUP materials and further information are available on the Web [4].

**Encouraging effective interactive learning**

An awareness of the following key principles for student learning is vital for the design of exercises, facilitator training and CUP classes [5].

- In the learning process each student constructs his/her own understanding.
- An atmosphere of trust promotes good learning.
- For active learning to take place, the ‘person in charge’ facilitates discussion rather than provides ‘correct answers’.
- Concepts are most readily understood if studied in a real-life context.

The CUP sessions assume a constructivist model of learning, i.e. each student comes with their own understanding based on what they already know and believe. They develop new understanding as they perceive new links between existing and new items of knowledge and beliefs. CUP exercises are specifically devised to challenge students’ existing conceptions and to encourage them to modify these when necessary.
The gravitational force $F_{GE}$ on the golf ball should be greater than $F_{FE}$ on the foam ball, and the air resistance $F_{GA}$ on the golf ball late in the fall should be greater than $F_{FA}$ on the foam ball.

The aim then is that within the three modes of each exercise a student reflects on her/his ideas, discusses and compares them with those of other students. This process enables students to become aware of and evaluate their beliefs, and to learn from each other new items of knowledge and new ways of linking ideas.

The process of seeking consensus further encourages students to reconstruct their understanding, where necessary, taking into account what they have learned in the preceding discussion. To achieve the goal of each student’s understanding being reconciled with correct physics concepts, it is important that students are clear about the final class consensus.

It is essential that students discuss their ideas freely. This is especially important where ideas are wrong or based on incorrect beliefs because these ideas and beliefs will need to be challenged if they are to be changed. As there is the risk of embarrassment or ridicule it is essential to build an atmosphere of trust in the class.

The facilitator helps build trust by explaining that everyone has some misconceptions which impede their conceptual understanding and that understanding can only improve if these are brought into the open and addressed. The facilitator needs to be exemplary in respecting students’ views.

Grouping the students into teams helps provide an environment where they feel ‘safe’ to discuss their ideas. It is the team’s response rather than each individual’s that is presented to the whole group. This gives students more confidence to participate in the whole group because each student knows that their comments will be supported by other members of the team.

In summary, students are engaged in active learning at each stage of a CUP exercise by sharing their own ideas, considering the consequences of others’ ideas, modifying ideas, forming a team consensus and arguing for it.

The CUP runneth over

The effectiveness of the programme was evaluated as part of a three-year project into student learning†. Interviews of a random sample of students and observations of CUP sessions were used to obtain a broad picture of students’ perceptions. Positive aspects frequently mentioned in interviews are listed below, with some students’ quotes.

- High level of enthusiasm
  ... the [CUP] group sessions were really terrific ... I think I found them more fun actually than the lectures.
  ... generally in tutorials in other subjects such as maths you just sit there and work. You can ask the demonstrator but it’s fairly quiet, not much noise . . . .

- Recognition of individuals and confidence

† The research project was funded by the Australian Research Council. An early report is given in [6].
They’re smaller groups of people, you didn’t feel like you were just one in a million ... in physics you feel like part of physics because it’s a small group.

This reflects our overall view that students perceive that recognition of them as individuals is conducive to a higher level of involvement. It is not simply the small numbers but the way that peer and student–facilitator interaction is structured which encourages greater confidence for a student to share his/her views.

People speak up a lot more with smaller groups ... you got to know these people better.

• Opportunity to discuss and modify prior beliefs

... if you’ve got ... people seeing things in different ways ... you’ve really got to challenge your own assumptions ...

... when you have to defend your own case saying this is the way it should go, you are actually learning ... and thinking about what others have to say, and how correct they are ... you don’t have that chance elsewhere.

• Awareness of the value of understanding concepts

The majority also recognized the value of clearly understanding concepts rather than doing quantitative problems.

If you didn’t understand something you could scream out ‘Why?’ ... I found I understood so much more than if someone was saying ‘Here’s the formula, write it down and go home and do a problem.’

• Awareness of how they were learning

In interviews, some students volunteered unexpected insights into how they thought they had learnt. Referring to the larger group,

... it gives you a different insight, like I hadn’t thought of that type of thing ... it gives you more to think about. See, physics is more concepts so you have to think about it to get anywhere, and if you have other people thinking differently, then your concept gets bigger.

• The opportunity to explore implications of concepts

I found it more fun ... get an idea and then try and work out all the possibilities ... and that’s mainly chopping around concepts and ideas.

CUP’s contribution to overall learning

Besides interviews, a further method of evaluation in the 1996 research programme was by survey. Students were asked which of the various aspects of their physics studies were helpful to their learning. A similar survey had been conducted in 1994, prior to the introduction of CUP. Both surveys included two open-ended questions. The first was ‘What one thing [in physics] most helped your learning?’ The responses in table 1 show that CUP sessions ranked third in 1996 even though of only six hours duration compared with 42 hours of lectures and 36 hours of laboratory in the semester.

The second open-ended survey question was ‘If there was one thing in the physics course you could change to help your learning, what would it be?’ Among a wide variety of suggestions, the most common response by far was ‘have more CUP group sessions’ (10%), followed by a related reply, ‘have small practice-class (tutorials)’ (6%). In 1994 the most popular response to the same question was ‘have small classes’ (15%).

The 1996 survey included five specific items relating to CUP sessions and learning. Two-thirds of students agreed that CUP sessions provided ‘the opportunity to clarify my ideas’. Taken together with the second open-ended item, this indicates to us that CUP sessions have filled a previously unmet need for many students.

The survey also lent support to our deduction from interviews that many students found the conceptual understanding developed in CUP sessions more valuable than doing quantitative problems.
Table 1. Responses to the open-ended survey question ‘What one thing most helped your learning?’.

<table>
<thead>
<tr>
<th>Response</th>
<th>1996 (%)</th>
<th>1994 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecture notes (class handouts)</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Laboratory classes</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>CUP group sessions</td>
<td>13</td>
<td>—</td>
</tr>
<tr>
<td>Lectures</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Textbook</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Computer-based mini-tests</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Asking questions of staff, assistants</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Private study</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Doing problems</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Other diverse responses, no response</td>
<td>24</td>
<td>32</td>
</tr>
</tbody>
</table>

We noted that female students in the interviews were positive about the group session but no further gender-specific studies have been conducted.

Continuing challenges

Students particularly valued reaching consensus, and their strongest criticism of the sessions related to disappointment if time constraints resulted in this being cut short. This criticism has helped improve exercises and facilitator training. It also is a strong indicator that students genuinely sought to understand rather than simply getting ‘the right answer’.

A reminder that different students appreciate different approaches for their learning came from the 1996 survey in which one third of students responded ‘I am not sure what I got from group sessions’. Student comments and observations during sessions suggest a number of possible contributing factors. First, the intense discussion may have been threatening to those who were shy, unsure of their physics or from different backgrounds to the majority of the class. Second, several students stated that the group sessions did not do ‘real physics’ (presumed to mean not using formulae to do quantitative problems). The numbers involved here were small. Third, some students may have been discouraged by not reaching ‘the final answer’, which was particularly likely to occur when exercises were too long and/or when facilitator inexperience led to poorly handled conclusions. Better facilitator training and improved exercises have helped reduce these difficulties.

In reaching an overall evaluation of CUP’s effectiveness, it is appropriate to remember that the concepts tackled in the group sessions were selected precisely because they are difficult for most students. For example, few students were competent on Newton’s Third Law or circular motion at the start of the semester. For the majority, CUP sessions succeeded in helping them realize and review their inconsistent views.

Conclusions

The structured exercises and cooperative learning approach used in CUP provide multiple opportunities for students to improve their understanding of basic concepts. Students enjoy and value the interaction. Initially trialled using troublesome concepts in introductory mechanics, it has applicability to conceptual understanding across a wide range of topics.

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References


