

*Participants of Professional Development Programme (Teaching) worked on research projects related to teaching and learning. This issue of CDTL Brief presents the first instalment of **Research Projects** done by the batch of PDP-T participants in April 2003.*

Socratic Method for Engineering Education

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I recently experimented with my classroom teaching experiment using the Socratic method with a graduate class at NUS. This experiment was inspired by the article, 'The Socratic Method: Teaching by Asking Instead of by Telling', written by Rick Garlikov. I was fortunate to obtain this article as part of the reading materials distributed at a seminar organised by the Centre for Development of Teaching and Learning, and was immediately fascinated by the teaching experiment conducted by Garlikov, in which he succeeded in teaching a regular third grade class in elementary school the subject of binary arithmetic only by asking them questions.

I knew that Socrates was a great Philosopher who had a unique way of teaching his disciples by asking them questions instead of preaching. But I had never imagined that such a method could be applied to other fields besides philosophy. If Garlikov could use the Socratic method to teach the difficult concept of binary numbers to elementary school kids, couldn't we also apply it to our engineering education?

The advantages of the Socratic method are obvious. It is one of the most efficient ways to get students involved because they have to figure out the answers by themselves most of the time. In the purest form of the Socratic method, questions (and only questions) are used to arouse curiosity as well as to guide the students logically to figure out a complex subject through their own thinking. When preparing the questions for my class, I found out that it was extremely difficult to adopt this pure form because of the complexity of the concepts and the time constraint. Therefore I decided to modify the Socratic method: when the students became stuck at some point, I would give them a hint or simply tell them the answer. When such kind of 'telling' happens, hopefully by that time, the students would have been sufficiently aroused by the questions to absorb an explanation with great interest.

This experiment was carried out during the first class on the topic of control systems design for the guided weapons, part of the MDTs (Master of Defense Technology and Systems Programme) Module 5705. There were thirty students in the class who were from the military. Two students were from the USA, and one from Israel. Two weeks before the class started, I emailed them to request their background information, in particular, how much they knew about systems and control. It turned out that they had diverse educational backgrounds such as electrical engineering, mechanical engineering, civil engineering, physics and even political sciences; unfortunately, most of them knew very little about control systems. I realised that I had a harder job than expected. Most of the questions were prepared before the class; but depending on what answers were given, some questions would have to be thought up spontaneously.

After a brief introduction of myself, I told them that my teaching style might be different from others. A lot of questions would be raised during the course and they were expected to figure them out by themselves or with my guidance. They could just call out the answer if they thought they knew it and did not have to raise their hands or wait for me to call up their names. But I would call upon their names if there were no volunteers. Since they were all from the military, I was afraid that they would keep silent initially. Quite surprisingly, many of them participated in the process right from the beginning and I never had to resort to calling upon names. As a matter of fact, they were much more responsive to my questions than the NUS undergraduates in my tutorial class. The fact that they were more mature and three of them were international students may have helped a lot in this perspective.

The following is the transcript of the beginning part of my lecture conducted on 23 August 2002:

XC: Have you ever heard anything about autopilot before? Where is it?

Student(s): Yeah, on the airplane!

XC: What's the usefulness of the autopilot for the plane?

(One student called out; the others laughed.)

Student(s): The autopilot can fly the plane when the pilot wants to sleep.

XC: Yeah. The autopilot can do some simple manoeuvring of the plane. But why do we need autopilot for a missile? Is it because the operator wants to have a rest too?

(The students were puzzled; nobody answered. Since I didn't expect them to answer this question directly, I carried on.)

XC: The task of a missile is to hit a certain target. In many cases, the missile may not fly in the right direction toward the target. For example, I want to hit the right corner on the bottom of the white board with the pencil in my hand.

(I aimed at the corner with my pencil and then threw it at it. But the pencil missed the target.)

XC: Why can't the pencil hit the target?

(One student called out; the others laughed.)

Student(s): Because it is out of control.

XC: Exactly. Once the pencil is out of my hand, it is out of control, and there is no way to correct its motion. To prevent this from happening for the missile, we need to build a control system to make sure that the missile is on the right track. Such a control system is also called an autopilot. With the help of the autopilot, the missile can correct its motion after it is launched and hit the target with high precision. However, the missile must be able to see the target in the first place, right? Then what are the eyes of the missile?

Student(s): The radar... the guidance system...

(I was quite pleased by the students' right answers since the part of the guidance system was just covered by my colleague before my session.)

XC: That's very good. The guidance system will tell the missile whether it is on the right track as well as how much correction it has to make, and the autopilot will follow the order and perform the right manoeuvres. The main focus of my lectures will be the fundamental principles for building an autopilot and some common design techniques. Flying a plane is kind of similar to driving a car. How many of you have driving experience?

(Some students raised their hands.)

XC: How do you steer your car in the right lane?

Student(s): I watch the road and turn the wheel.

XC: Very good. You have to constantly monitor

the road condition and decide whether you should turn the wheel or not. Such kind of process consists of three steps: measurement, comparison, and correction. In control theory, we call it FEEDBACK. It is the fundamental principle for all the self-regulating systems, natural or man-made. Therefore, you should not drive when you are drunk because you would not be an efficient feedback controller!

(Everybody laughed.)

XC: To be a good teacher, I also have to be a feedback system instead of spoon-feeding. So if you have any questions or comments, you may interrupt my lecture at any time, talk to me after the class or email me. Don't be afraid to make mistakes in the class. If you make mistakes here and get corrected, then you will not repeat the mistake in your final exam.

(They all nodded.)

XC: O.K. Since most of you have very little background in systems and control, we'd better start from the scratch. I believe that 'system' is one of the most commonly used words in science and technology. But what is a 'system'?

(The students hesitated a little bit, and finally one guy attempted an answer.)

Student(s): A set of elements.

XC: You are almost right. Intuitively, we can consider a 'system' to be a set of interacting components subject to various inputs and producing various outputs. In fact, a 'system' is such a general concept that there is no universally accepted definition. It is like the concept of a 'set' in mathematics, everyone knows what a 'set' is, but we cannot define a 'set'! Similarly, we cannot define a system! But we are all familiar with many different types of systems. For example, the mechanical systems. Can you list some of them?

Student(s): Clocks... pistons...

(I wrote the students' answers down on a transparency film that was projected via an overhead projector.)

XC: Electrical systems?

Student(s): Radios... TVs...

XC: Electrical-mechanical-chemical systems?

Student(s): Cars... hard-disk drives...

XC: Industrial systems?

Student(s): Microsoft company...

XC: Medical systems?

Student(s): Hospitals...

XC: Educational systems?

Student(s): NUS...

XC: Biological systems?

Student(s): Animals... human beings...

XC: Information processing systems?
 Student(s): Computers...
 XC: This brief list is sufficient to emphasise the fact that one of the most profound concepts in current culture is that of a 'system'. Now if I ask you to classify all the systems into two broad categories, what would you say?

(After some thought, one guy called out.)

Student(s): Animate and lifeless...
 XC: Another way?
 Student(s): Natural and man-made...
 XC: Can you classify them in terms of mathematical properties?

(The students all hesitated, and someone murmured.)

Student(s): Continuous time and discrete time...
(This was a right answer, but not what I aimed at.)

XC: Another try?
(After about one minute of contemplation, one guy finally called out.)

Student(s): Linear and non-linear...
 XC: You got that right! Excellent! But what's the fundamental difference between linear and non-linear systems? Now imagine that I give you two black boxes to choose. One is linear and another one is non-linear. There are one million dollars inside the linear box, while a tiger in the non-linear one. You can take away one of the boxes, and you are allowed to use any types of inputs to probe the black boxes. But you cannot open either one. What's your winning strategy?

Student(s): Pump in a constant input and the output of the linear one should be a constant.

XC: But the output of the non-linear one could be constant too. Another try?

Student(s): Pump in a sinusoid and the output of the linear one should be a sinusoid.

(I was quite pleased to hear this answer, which showed that the student knew something about frequency response of the linear system. But it was not what I looked for.)

XC: But the output of the non-linear one could also be a sinusoid. Another try?

(This time it seemed that they really got stuck, and I decided to bail them out.)

XC: Do you want any hints?

(One student called out; the others laughed.)

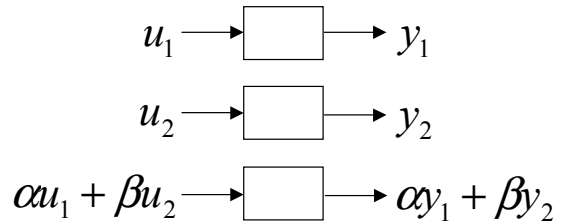
Student(s): Yeah, give us a hint...
 XC: How about the superposition principle? Have you ever heard of that?

(One student called out the answer immediately.)

Student(s): I've got it! I pump in two different inputs and record the outputs. And then pump in

a third one that is the summation of the previous two. The output of the linear system should be also the summation of the previous two outputs.

XC: Well done!
(I then drew the following diagram to explain the superposition property of a linear system.)



XC: Superposition property is the most fundamental property of a linear system. Just because of this, linear systems are much easier to analyse than non-linear ones. Now come the good news and the bad news regarding the real world systems. Which one do you want to hear first?

Student(s): The good news...
 XC: O.K. The good news is that many non-linear systems can be well approximated by linear systems. The bad news is that linear approximation is good only locally, in other words, only in a neighbourhood around certain operating points. Most real world systems are non-linear systems, which is indeed a very fortunate thing. That's why the world is full of wonders.

Of course, the systems will rarely be black boxes as in the previous million-dollar question. In fact, many systems can be described by mathematical equations, like the spring-mass-damper system. The equations can be derived by Newton's second law. We will do the same thing with missiles later.

Once we write down the equations, the next step naturally is to analyse or even solve the equations. As all of you know something about calculus, can you solve following differential equation?

(I wrote down the following homogenous first order differential equation on the slide.)

$$\frac{dx}{dt} + x = 0, x(0) = 1 \quad (1)$$

(One student called out the right solution.)

Student(s): e^{-t}

XC: You are good. How about this one?
[I added an external input u(t) in term in the previous equation (1).]

$$\frac{dx}{dt} + x = u(t), x(0) = 1 \quad (2)$$

(It seemed that they could not recall the right formula for this problem, just as I had expected.)

XC: Not an easy one, right? Then how about this one?

[I wrote down an algebraic equation where s replaced the differential operator d/dt in equation (2).]

$$sX + X = u \quad (3)$$

(The solution was trivial, and one student immediately called out the answer.)

XC: All right. Equation (3) is very easy to solve because it is a simple algebraic equation. Equation (2) is not so easy because it is a differential equation with an external force term. Now I am going to show you a trick that can turn the problem of solving equation (2) into the problem of solving (3), does that sound good?

Student(s): Good...

Following that, I explained the Laplace transform, which is a powerful tool of solving differential equations. The rest of the transcript is omitted here since it contains too many technical details that may not be interesting for general readers. Nevertheless, I hope this short transcript is sufficient to prove that the Socratic method can be applied to engineering education effectively.

The main advantages of the Socratic method are:

- it arouses students' curiosity and stimulates their thinking, rather than spoon-feeding them;
- it makes teaching more enjoyable for both the teacher and the students as they interact with each other and learn from each other; and
- it gives constant feedback and thus allows the teacher to monitor of the students' understanding as he/she proceeds with the class.

By comparison, a teacher can lecture in much less time. For instance, I could simply have stated in one sentence (which is more time-efficient) that the fundamental difference between the linear and non-linear systems is the superposition property. However, I believed that the students would be better stimulated by thinking about the million-dollar puzzle. Hence, the Socratic method is more efficient in helping students think, understand and learn material.

Although the Socratic method seems a perfect approach for teaching almost any subject, it is much harder to adopt than the traditional way of telling. There are big challenges that the practitioner has to face:

- It is first necessary to change one's mind-set or teaching philosophy. The teacher must accept that excellent teaching is not about just giving a nice presentation, but

rather about helping the students to really understand and learn some thing. Otherwise, the teacher would never bother adopt this method of teaching by asking questions.

- The next challenge is how to prepare the questions that are interesting and logically leading. Not any question will do. That is the whole point of the method. Undoubtedly, asking the proper questions in the proper order is more of an art than technique, and there is no recipe to follow other than persistent practice.

I have to admit that the questions I designed were far from ideal since I am just a beginner in this art. Nevertheless, I believe the following guidelines, derived from my experience, may prove useful to those who wish to practise the Socratic method:

- **Always stick to the principle of 'teach by asking instead of telling'**. Whenever you want to convey some idea, always try to do it by asking questions, and consider 'telling' only as the last straw. This guideline is hard to follow because 'telling' is always an easy way out.
- **Play the role of the student**, and ask yourself: "What would I answer if I were asked this question?" In other words, you have to imagine the students' responses, which will in turn help you structure your next question. This is the best way I can think of deciding the sequence of the questions. Preparing the questions for the class becomes 'writing a play' to some degree. Of course in the real classroom, the students will surprise you in different ways: you may be pleased that they are cleverer than you thought or you may have to come up with new questions on the spot. Thus prior preparation is vital, as it will help you to improvise when you need to do so.
- **Start with some thing that the student may be familiar with**. For instance, although I wanted to ask the students about the purpose of having autopilot for missiles from the very beginning, I realised that some students might not be aware of such a feature on a missile, while most of them should know about autopilot on planes. Hence, I began with a general question of whether they knew anything about autopilot or not.
- **Ask specific questions; avoid broad, open-ended questions**. Otherwise, students will have nothing in particular to focus on and few will come up with the answer that you are looking for. For example, the question about classifying systems into two broad categories turned out to be not specific enough because there are so many ways to classify systems. In contrast, the question about classifying systems in terms of mathematical properties was more specific and helped the students to could focus and narrow their choices till they arrived at the expected answer.

The task of preparing questions forces the teacher to think about the logic of a topic and how it can be most easily assimilated, as well as to play the roles of both lecturer and students. Obviously, it is much more mind-boggling and time-consuming than simply preparing the traditional lecture

notes. However, this investment of time and energy is worth the while. In my case, the students appreciated my efforts; one of them sent me a message saying: "I think I would say this for the class that we are very fortunate to have you as our lecturer."

Reference

Garlikov, Rick. (11 June 2000). 'The Socratic Method: Teaching by Asking Instead of by Telling'. http://www.garlikov.com/Soc_Meth.html (Last accessed: 23 July 2003). ■

A Survey of Tutorial Preparation and Participation

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Introduction

We are new to teaching in NUS and we experienced low level of participation in tutorials. Is there anything that we can do about it? We believe that as instructors, we can influence the level of preparation and participation by carefully designing tutorials, and by adopting better pedagogical techniques. The first step towards testing our beliefs is to understand the factors that affect students' attitudes concerning preparation and participation. Hence, we conducted a survey among our students for this purpose.

Survey

We postulated the following hypothesis:

More preparation for the tutorial increases participation.

Over a week in March 2003, the survey was conducted during regular class hours. Taking the form of a questionnaire, it consisted of 34 questions. Here are three sample questions:

During tutorials, I participate by:				
Asking questions	never	sometimes	often	always
Engaging in discussions	never	sometimes	often	always
Volunteering to solve problems	never	sometimes	often	always

This survey design was guided only by common sense, not by any rigorous scientific theory. To encourage students to be honest with their answers, the survey was done anonymously, and the instructor was not allowed to be present in the classroom. Unfortunately, due to time and resource constraints, we could not reach all our students. Only those that happened to be in class on that particular day took the survey. This resulted in a small sample size: only 54 respondents in total. This in turn means that our survey results may not be representative of the attitudes of the general student population. Other background information is shown in Table 1.

Total number of respondents	54
Number of female students	27
Number of male students	27
Breakdown by level	
Level 1000 course	38
Level 4000 + postgraduate course	16
Faculties involved	School of Computing Faculty of Arts and Social Science

Table 1: General survey information

Analysis

We only report some of our results here: level of preparation and participation, differences by gender and differences by module levels.

Level of preparation and participation

Figures 1 and 2 show the overall preparation and participation levels. More specifically, Figure 1 shows the percentage of respondents who prepared for tutorials, broken down by the type of preparation: reading lecture notes/journal articles (for postgraduates only)/textbook, attempting to answer some or all of the tutorial questions. Most students attempted at least one question (76%), although few read the textbook (30%). There seemed to be a preference for lecture notes over textbook (43% vs. 30%) when it comes to preparation. We conjectured that this might be because lecture notes are more concise, requiring less time to read than textbooks. The primary reason students gave for not preparing for tutorials is that they were busy with other courses. For those who prepared, they did so to learn more about the subject material.

In contrast, tutorial participation was disappointingly low, which was consistent with our observation (see Figure 2). Fewer than 35% of respondents engaged in discussions, or asked questions. Fewer still volunteered to solve problems. These findings agreed with our personal experience. More often than not, we have had to coax students to participate lest the class quickly degenerated into another lecture. The

main reasons students gave for not participating were: (a) the fear of getting the wrong answer, and (b) not wanting to be perceived as a smart aleck by other students.

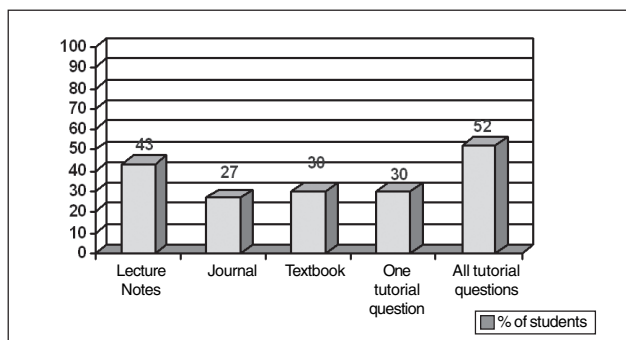


Figure 1: Overall preparation level
The students were asked which document they read/which questions they attempted before going to a tutorial.

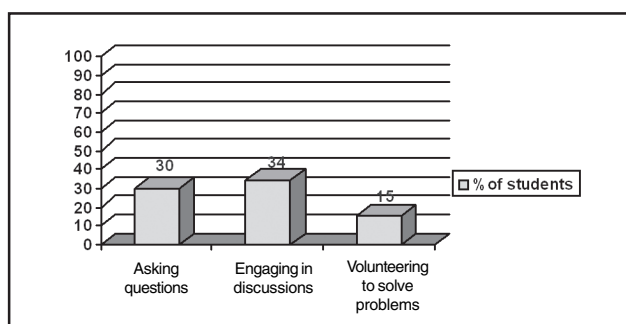


Figure 2: Overall participation level.

In terms of correlation analysis, we were surprised by the low positive correlation between preparation and participation: 0.2784. This appeared to provide weak evidence for our hypothesis that those who prepare more would be more active in class.

Differences in Gender

These statistics are more interesting. Note that there were equal numbers of male and female respondents. Figure 3 shows that males and females differed most in reading and answering the tutorial questions before coming to class. Females tried to solve all the given tutorial problems twice more often than males do (67% vs. 37%). Moreover, males preferred to read the textbook (37% vs. 22%). This may be because they were less attentive in lectures than females. Unfortunately, we did not measure lecture attentiveness in our survey.

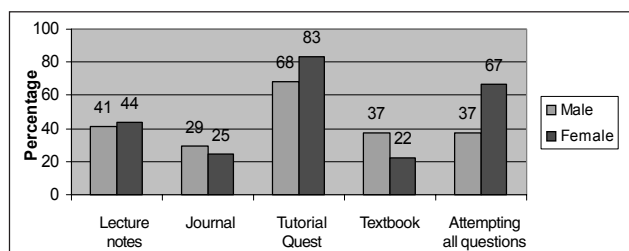


Figure 3: Preparation by Gender

While females appeared to prepare more, the situation was reversed for participation. Male students were more active in asking and discussing questions in class. Figure 4 shows 44% versus 15% (for asking), and 44% versus 22% (for discussion). If we combine this fact with our earlier observation, it seems to say that while men prepare less than women, they nonetheless talk more in class! One wonders where the men get the knowledge to talk intelligibly. Is it a case of the empty vessel making the most noise? Note that this situation might be unrelated to the issue that we raised (namely the relationship between preparation and participation), and was more likely to be entirely due to gender difference issues. However, we did not want to consider such themes, as they were not the focus of our survey.

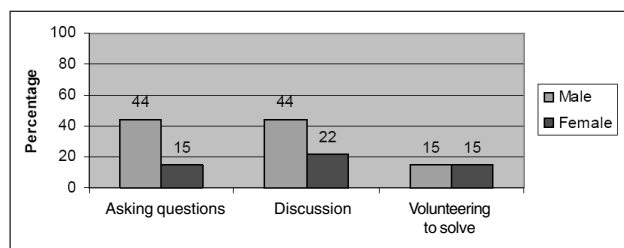


Figure 4: Participation by Gender

Differences by module levels

We next looked at the statistics by module levels to see if older students were more likely to participate compared with younger ones. Figures 5 and 6 show that they do. In these figures, we defined upperclassmen as students taking 4000-level courses and above. This agreed closely with their actual age: the 1000-level course enrolled mostly first-year undergraduates, while the upper-level courses were taken by students having had at least three years of university education. It is clear from the figures that older students were better prepared for tutorials than the younger ones, and they also participated significantly more. However, because the number of upperclassmen was less than half of the number of freshmen (16 versus 38), our result could be biased. It may also be that students do not change their attitudes over time. However, those who have the best preparation for tutorials obtain higher marks in the exams, and hence are more likely to reach the fourth year of study or enter a graduate school.

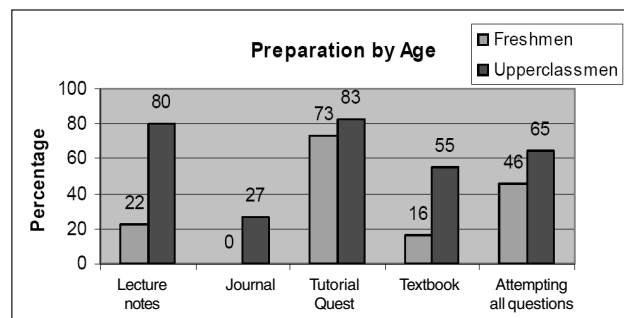


Figure 5: Preparation by Module Levels

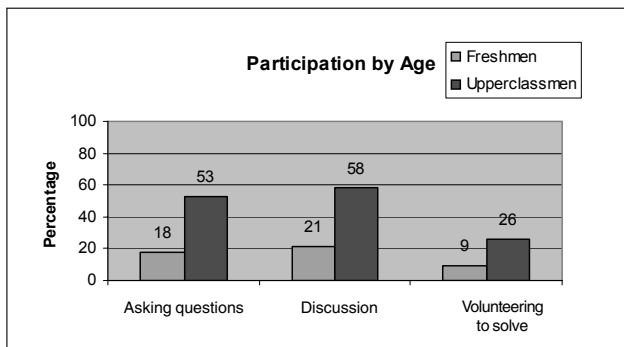


Figure 6: Participation by Module Levels

Conclusions and implications for teaching

We conclude this report with a summary of the main findings of our survey:

- There was relatively weak correlation between tutorial preparation and participation.
- The main reason for not preparing for tutorials was that students were busy with other courses.
- The main reasons for not participating were: (a) the fear of getting a wrong answer, and (b) not wanting to be perceived as a smart aleck.
- Female students appeared to be better prepared than male students, but they participated a lot less.
- Older students prepared and participated more than younger ones.

Interestingly, we also found that the quality of teaching did not significantly affect preparation. Teaching well was only a weak reason why students prepared for tutorials (Main reason: Students recognised that they learnt more if they come better prepared.). Conversely, teaching poorly was not a reason why students did not prepare (Main reason: They were busy with other courses). This suggests that there is little we as instructors can do to influence students' behaviour. Students are busy with other coursework partly

because of university course requirements, and partly because of their priorities. However, this does require us to design a proper tutorial handout which takes consideration of available time students have apart from other academic activities. Our suggestions include the following:

1. The tutorial handouts for freshmen should start with easy questions; students don't participate much and difficult questions will make it worse. Handouts should refer to specific parts of the lecture notes, as the students may not have read them entirely beforehand.
2. Older students usually prepare well and participate more; so the suggestion above does not apply in their case. We would recommend that handouts for older students contain more challenging questions that will encourage longer discussions and at a higher level.
3. Minimise students' 'fears' (i.e. the fears of getting a wrong answer and being perceived as a smart aleck) by having smaller groups with a non-structured tutorial format and building up a close relation with students.

Our observations also suggest the following strategies while conducting the tutorial:

4. Preparation and participation are not correlated, which means that the students who participate most may not have the most useful contributions. Therefore, we recommend that the tutor initiate the discussion by asking directly a random student for the answer. Such a measure will not decrease the level of the tutorial; in addition, this allows gender (and other) bias to be corrected.
5. If a tutor would like to boost students' participations during tutorials, ask male students to answer the first question since they prepare only for one question (it will likely be the first one), and direct the rest of your questions to female students since they tend to prepare for the whole tutorial. ■

Increasing Student Participation: A Classroom Experiment

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At the Department of Computer Science, some of the undergraduate courses have large student enrolments. This is especially so for the lower level undergraduate courses. Lecturing to a large class poses some challenges. Typically, there is limited student interaction during each lecture. Consequently, how to increase student participation during lectures in order to facilitate teacher-student and student-student interaction becomes an important issue.

In this short article, I will share my experience in a classroom experiment conducted with the aim of increasing student participation. The experiment took place during Semester 2 of Academic Year 2002/03. The class involved had more than 170 students, mostly second-year undergraduates majoring in computer science. The course covered introductory artificial intelligence.

Ingredients of the experiment

One way to increase student participation is for the teacher to pose questions to the students. The hope is that students will be forced to think and reason when faced with questions, and that answering the questions gives them an opportunity to interact with the teacher. However, this approach of posing questions may not work well in practice. Lecturers and students are all too familiar with the situation when a question posed is met with deafening silence. Even after repeated prompting, students are still too shy to volunteer to answer the question. A better way to encourage students to speak up is needed.

In my experiment, after I posed the question, I first got the students to discuss in groups of two (i.e. each student discussed the question with his/her neighbour seated next to him/her) for two minutes. This serves as an icebreaker, since students are generally less inhibited when they engage in small-group discussions. It also achieves the aim of increasing student-to-student interaction during the lecture.

In order to challenge the students to engage in higher-order thinking, a question that leads the students to relate different parts of the course material and to 'see the big picture' is preferable, instead of a question that asks them to regurgitate facts. In the experiment, the lecture topic was on machine learning. The question I asked was: "Give an algorithm to generate a good decision tree that maps an example to a category, given a set of examples with assigned categories."

At the point of posing this question, I had not touched on any learning algorithms. However, earlier topics of the course covered include search, representation and inference, and planning. It was pointed out to the students before that both inference and planning could be viewed as a search procedure. Hence, a deep understanding of these previous topics would enable a student to come up with an answer to the question posed (i.e. a search algorithm that views learning as search).

Another aspect of increasing class participation is to engage students in a discussion, instead of a one-way process of posing a question and getting an answer back. This can be brought about by asking sub-questions whose answers then lead to more subsequent questions. In this way, the teacher can provide hints and build upon the students' partial answers, and foster an interactive discussion in the process.

Outcome of the experiment

After warming up by discussing with their fellow students first, the students were less inhibited in answering the question. After some hints and prompting, one student was able to come up with the correct answer. In the process, another student even asked me to clarify a point.

Overall, the outcome of this experiment is that the students did develop a deeper understanding of the connection between the different parts of the course material. The students became more active in class participation, not only in answering the question, but also volunteering to ask a related clarification question about the topic. The classroom atmosphere became livelier as a result.

Pausing a lecture to get students to first discuss among themselves a higher-order question takes up a bit more time. However, this practice does break the monotony of lecture and its occasional use brings benefits and increases student participation in a large class. ■



The Centre for Development of Teaching and Learning (CDTL) engages in a wide range of activities to promote good teaching and learning at the National University of Singapore, including professional development, teaching and learning support, research on educational issues, and instructional design and development.

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