Think with Your Hands: Some Thoughts about Teaching Engineering Mechanics and Mathematics to Civil Engineering Undergraduates

By ／ Hervé Capart 卡艾偉
(Associate professor, Dept of Civil Engineering.)

How should we go about teaching mathematics and mechanics to our engineering undergraduates? Can we get students to sit up and get involved with the material, instead of sitting back and waiting for the lecture to end? Can we offer them, in the classroom or in the lab, things that they can' t find on their own in the textbook or on the internet? I wish to suggest here a few personal answers to these questions, based on my limited experience of these last five years as a foreign instructor in the Department of Civil Engineering of National Taiwan University.

Our students

Why not start with our students? Who are they, what do they seek, and what do they need? I have not done any scientific survey, but there are a few differences between engineering students in Taiwan and in Belgium (my home country) which I could not help but notice. First, the mainly Taiwanese students who pursue civil engineering at National Taiwan University don' t seem quite convinced that they really want to pursue civil engineering as a career. They' re open to the idea, but they' d like us to give them some good reasons not to bolt towards other career paths at the first opportunity. The reason for this appears to be the rather early and constrained choice that they' re asked to make, straight out of high school, depenent on their performance on the university entrance exams. Students who get in might have made another first choice, or they might have wished to study a broader field of study (say, engineering in general), before committing to the narrower field of civil engineering.

The implication for us instructors is that we haven' t yet closed the sale. If we hope to convince students that their partly accidental field of study is worthy of their hopes and efforts, we need to show them why. I feel that one way to do so is to expose them as early as possible to the interesting applications of the concepts that they encounter in basic courses, without waiting for the applied courses of the last years of undergraduate study.

This can be done without creating new courses, by designing problems in mathematics and mechanics that have a stronger engineering flavour.

There seem to be other consequences to the intense cramming that Taiwanese students go through in their high school years. First, their technical skills, such as those involved in memory tasks, textbook reading, or mathematical operations and calculations, are very good. Secondly, once entrance exams are over and they’re made it to university, they’re hungry for social interactions of all kinds. Thirdly, because of their forced focus on intellectual tasks during high school, most of our undergraduate students haven’t had the chance to develop much the design and manual skills involved in actually constructing things. One final characteristic of this generation, this one shared the world over, is that these students are heavily exposed to virtual contents, and don’t need any help from us in finding their way around cyberspace.

At the Department of Civil Engineering, what then do we have to offer students that they can’t find on their own in the textbook or on the internet? It seems to me that two good places to start are the classroom and the laboratory. These two most traditional places may appear quaint in the age of “distance learning”. I believe, however, that they are precisely the locations where we can compete most effectively with other media. The classroom and the lab are two places where we can try to take maximum advantage of the many possibilities of “proximal learning”, the learning that takes place when people are in the direct company of each other. The next two sections present a few approaches which I have been experimenting with these last years, and which have generated good student feedback. I will not mention those other experiments which have miserably failed.

文承13頁

師嚴謹的課程淬練，豐碩了我的羽翼；Meshii教授對我的信任與尊重帶領著我能以「不卑不亢」的態度在學術的殿堂與先進切磋，其謙沖、沒有學術狂妄的治學態度，更成爲我督促自己的座右銘。現在，自己身爲人師，面對年輕的莘莘學子，我愈來愈能體會當年眾多恩師提攜的用心。帶領著一群優秀的年輕人，在浩瀚的學海裡，用智慧、用道德、用真心，一代又一代的薪火相傳，我想爲人師者最大的喜悅應莫過於此吧！（本文策畫／材料系莊東漢教授）

學生的感謝

文／陳懋德

某天午後的「物理冶金」，我在課堂中第一次認識了老師。老師給我的第一印象，除了親切以外，還有一股相當值得信賴的感覺。老師對學生的認真和重視，都可以在每堂課爲我們編寫的講義表露無遺。很多在課本上乍看像是天書的原文字句，老師都用心地把它們編成易懂的圖片。身爲本校材料系第一屆的大學部學生，我深深地對於能夠在老師的實驗室繼續攻讀碩士感到很幸運。我想我永遠都會記得在進入研究所、決定指導教授的時候，老師對我說：「老師希望你可以進入你最想進的實驗室，所以老師可以幫你完成一個願望。你想要跟隨那一個教授，老師都可以幫你推薦。」或許多數的教授在學生的眼中，都是遙不可及、高不可攀的。但是我的老師不僅是位良師、還是位可遇不可求的益友。在研究所的第一年，我可以在與老師充分的溝通、及在老師細心的指導下，感受沉浸在學術中的美妙滋味。所以，我要在這邊謝謝我的老師，謝謝他完成了我的願望，謝謝他讓我進入了我最想進的實驗室。（學生陳懋德寫於95年教師節前夕）

Classroom tasks

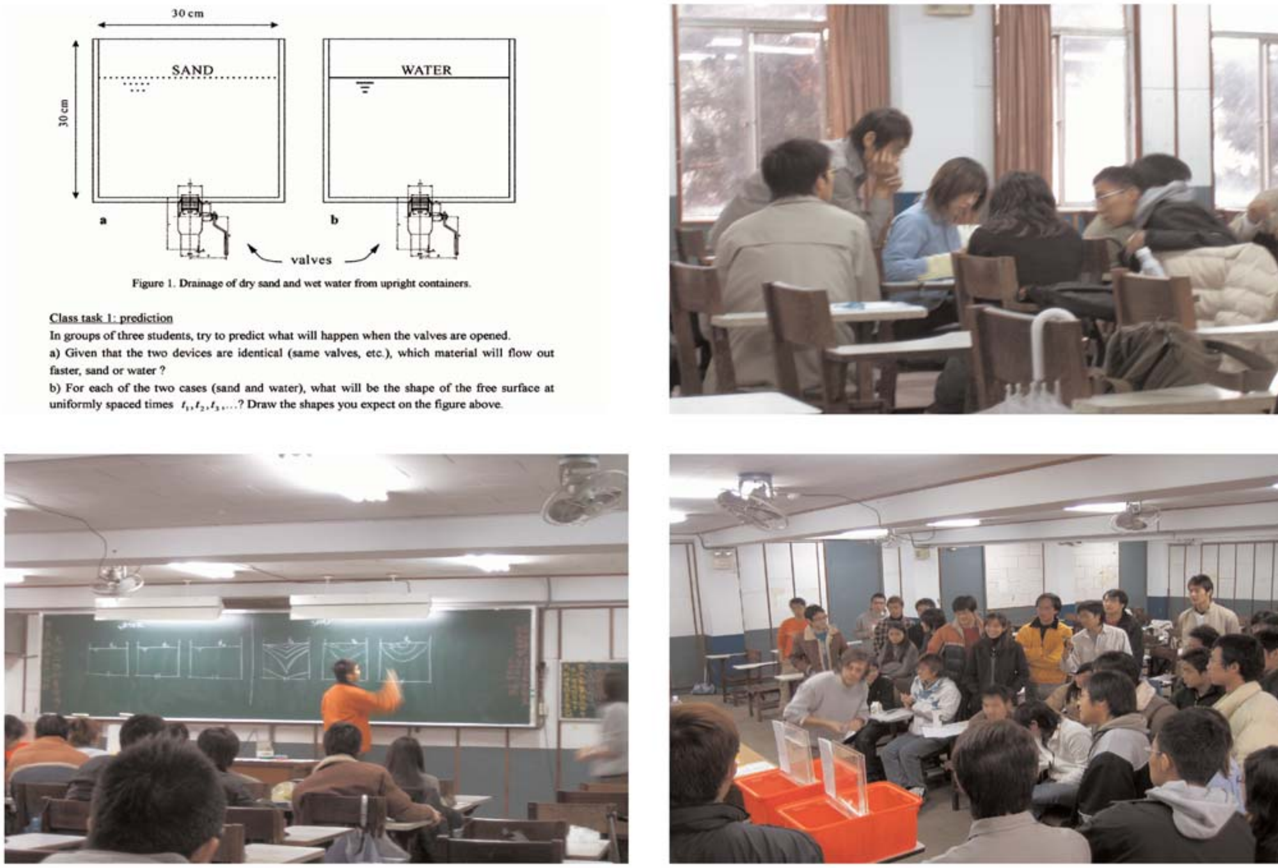
Consider the advantages of the classroom. In a confined space, all you have to do is to wait for the students and close the doors, and there you have a captive audience. One can then turn off the lights and try to put up a good multimedia show, complete with movies and slides. While this may get the audience captivated, however, it has the major drawback that it also gets the audience "passivated", sitting back and taking in the sights and sounds. How about turning the lights back on, and trying to get the audience "activated" instead? One way to do this is to give students things to do, as early and as often as possible.

As an example, a sequence of activities that I have proposed to students in the first lecture of a course on fluid mechanics is illustrated in Figure 1. The class starts with the question "what is a fluid?", asked in reference to two experiments. Both experiments involve transparent tanks with a valve at the bottom, closed for the moment being. One tank is filled with dry sand, and the other is filled with pure water. The tanks are in front of the class, and the experiments are ready to be performed, but students are asked first to think about what will happen. How will sand and water flow out? In particular, what will be the shape of the free surface as each experiment proceeds? Students are given a Xeroxed worksheet, with explanations and blank figures, on which they are to draw the flow pattern and surface profiles that they expect. Students are given some time (10 minutes), to discuss in small groups and arrive at predictions. The instructor walks around to check that everyone understands the question and to encourage everybody to stay focused on the task.

Next, volunteers from different groups are asked to draw their predictions on the blackboard. If all goes well, different groups will propose different views. The instructor can point out differences and ask students to explain their thinking. In limited time, not every group can draw on the backboard, but all groups are asked to hand in their "prediction" worksheet to the instructor. Only then are the demonstration experiments performed, with students assembled around the set-up (see photos in Figure 1). Students can thus confront their intuition with actual experiments. The observations can later be used to underline the specific characteristics of fluids, as opposed for instance to the behaviour of granular media like dry sand. The reader is also encouraged to make a prediction for the record before trying out such experiments!

Of course, it is not possible to carry out a complete sequence of this kin in every lecture. There are, however, a number of other steps that I have found useful to get civil engineering students more actively involved in courses on mechanics, mathematics, and statistics. One very useful step is to complement the textbook with handouts and hand-ins, delivered piecemeal in class as Xeroxed copies. Typically, one handout given at the beginning of a class will summarize the relevant theory, and present an exercise problem, often related to an engineering application. A work sheet with ample blank space will also be provided to the students, on which they can work alone or in small groups. During a task, a teaching assistant can join the instructor in walking around the class to help students address the problem. At the end of the task, students will hand in their worksheet, and receive in exchange a new handout with the teacher's proposed solution to the problem.

Time management is greatly facilitated by the hand-to-hand delivery of Xeroxed handouts and hand-ins. The teacher can save time, and pace the flow of information. The class time saved by replacing a blackboard presentation of a step-by-step solution with a printed handout can be used to let students work themselves on the problem. By using handouts instead of textbook examples, the teacher can also withhold the solution until after students have worked on the problem. One thus avoids having students flip through the textbook to read the solution without having first tried to work it out on their own. To preserve these advantages, handouts are only given in paper form, one by one, as the semester proceeds. They are not posted on the internet: students must come to class or contact their peers to get a copy.



■Figure 1. Class task example (undergraduate course in fluid mechanics). From left to right and top to bottom: students are asked to predict how sand and water will flow out of a 2D silo; they think about the problem; they report their predictions to the class; we look at actual experiments. Photos by Ke W.T.

The use of one's own handouts has another great advantage, which is to allow customization of class problems to civil engineering applications relevant to Taiwan. The environment of Taiwan, rich in both civil engineering landmarks and natural hazards, is especially suited to this type of treatment. Problems in statistics can involve typhoon recurrence and debris flow paths. Linear vector spaces can be applied to traffic flow at busy intersections, and ordinary differential equations can describe the vibration modes of buildings subject to earthquake shaking. Possibilities of this kind are endless, and many students do seem to take a greater interest in a mathematical technique when they see how it can be applied to a real-life civil engineering problem. Such specific applications are often missing from textbooks addressed at a less well-defined international audience of engineering students from all disciplines. This of course does not mean that we should write our own textbooks, which is a considerable undertaking. Handouts that complement the textbook with customized problems constitute a more economical approach, in addition to their time management advantages.

Another powerful way to encourage students to work in class is to schedule mock exams at the end of a chapter. Problems representative of those encountered on actual tests are provided in a handout, and students are encouraged to work on them during one full class period. During this period, they are encouraged to discuss the problems with other students, with the instructor, and with a teaching assistant when one is available. At the end of the mock exam, the teacher provides a second handout with proposed solutions to the problems. I have found that this type of practice session often generates a great deal of interaction between instructor and students. Whereas students seldom come knock on the office door to ask questions outside of class, they appear receptive to in-class interactions in which the teacher walks around to see how they are doing. Also, students appear to benefit a great deal from interacting with each other. Students who lag behind come under some pressure by seeing how their classmates are able to solve the problems, and the brighter students benefit from explaining concepts and methods to others.

Laboratory projects

Another great venue for "proximal learning" is the laboratory, where different types of activities can take place. One first type of activity involves demonstration or teaching experiments. For such experiments, the set-up and procedure has been prepared in advance by the instructor or by laboratory technicians, and the students are invited to observe phenomena or manipulate the instrumentation. A limitation of this approach is that students have not been involved in the design of the apparatus or experiments. A second type of activity is the design project, in which students come to the laboratory to test their own design and construction skills. With teaching assistant Li C.Y., we tried this approach for an introductory course in fluid mechanics, and the process we adopted is illustrated in Fig. 2.

Since the fluid mechanics course is not primarily devoted to experiments (students have a separate laboratory course that they take the following year), the design project was set-up as an elective, out-of-class activity for students wishing to participate. The grade from the project would then be averaged in with the scores from traditional written exams. Participating students were asked to work in pairs, for a total of 5 sessions of one hour each, to design and build a special type of hydraulic device. The device is a self-closing flood gate, open during low discharge, but which must be able to safely close itself without human intervention for high water levels. The device has to meet some basic specifications, and must be testable in a hydraulic flume of known dimensions and flow conditions. The manner in which specifications were to be met, however, was left completely open, allowing for a variety of possible designs.

To illustrate what we expected from the students, we prepared an example of another device, a self-opening gate, which functions in the opposite way as the self-closing gates to be designed by the students. A self-opening gate, or fuse gate, is a flood gate placed on top of a dam spillway that is designed to open on its own once the discharge exceeds a predefined threshold. We prepared a small acrylic model of our design, and presented it to the students during the first session of the project. We used this example to illustrate the three steps of the project: 1) design; 2) build; 3) test. In the design part, a basic operating principle must be chosen, and refined using fluid mechanics concepts such as hydrostatic pressure and moments. To build a device, one must choose some simple materials and techniques such as acrylic panels and O-rings. Finally, the device must be tested in actual flow experiments. Demonstration tests of our device were carried out in the same flume that students were to use for their self-closing gate.

Working in pairs, the students then started working on their designs, with feedback from us. Once preliminary designs were ready, students were to procure their materials (a small budget of 200 NT$ was allocated to each group), and to actually build their device (see photos in Fig. 2). To our delight, students came up with a great variety of operating principles and designs, based on levers, wheels, floats, etc. (see photos for a few examples). Students were allowed to conduct preliminary tests of their design and revise any flaws by testing their device in the laboratory flume. Finally, the last session of the project was devoted to the evaluation, in which students were first asked to present their device and explain its design, then to test it in the lab flume under actual flow conditions.

The project was quite fun, both for us and the students, due to the pleasure of building things, playing with water, and seeing how different people find different solutions to the same design problem. It also provided a number of interesting learning opportunities. Participating students had to confront the gap between theory and practice. For example, water-tight walls of zero thickness are often assumed when solving a fluid mechanics exercise. In practice, the walls have thickness, and water-tightness is difficult to achieve without special means such as

文轉21頁

■Figure 2. Laboratory project example (undergraduate course in fluid mechanics). Students were shown a demo of a teacher-designed self-opening fuse gate (top left), and were tasked to design and build on their own (top right) a self-closing flood gate. The middle row shows two student designs. For the final jury, students were to install and test their design in a laboratory flume (bottom row). Photos by Ke W.T.