Active learning in quantitative disciplines

Image:http://www.freeimageslive.com/galleries/workplace/education/pics/square_numbers.jpg

Although there is no single definition of what 'active learning in the classroom' constitutes, they are all based upon the idea that students' learning performance is improved by being given opportunities to directly engage with content during classes, seminars and lectures, either through individual work or collaborative work with peers. These engagements usually demand a high level of cognitive activity for example, requiring students to make explicit links to mathematical concepts (rather than making these for them), asking them to critically evaluate ideas or even create new ones.

The impact such interventions can have on students' learning has been seen (Freeman *et al*, 2014; Bell and Kozlowski, 2008) to include:

- Increasing the examination performance of students
- Reducing course failure rates and increasing student retention
- Improving students' knowledge transfer capabilities (e.g. seeing brand new questions on previously seen material)
- Improving students' attitudes and reducing anxiety

This document discusses approaches to *classroom* teaching in quantitative subjects that can increase the level of student engagement in your classroom. To help you develop this aspect of your teaching, it first identifies four areas, or *dimensions*, of good teaching practice, and then provides several prompt questions for each to help you review your current approach. Do not feel the need to address *all* these questions at once: indeed, better progress can be made by focussing on a few changes at a time, so that you can better monitor their impact and success.

A key aspect of each of these questions is that the changes they prompt are easily observable and measurable to better facilitate such monitoring and continuous development.

This paper is intended as a standalone companion to the paper PORTAAL: A Classroom Observation Tool Assessing Evidence-Based Teaching Practices for Active Learning in Large Science, Technology, Engineering, and Mathematics Classes, (Eddy *et al*, 2015), which not only discusses the ideas here in more detail but provides a wealth of references for you to further explore.

If you would like to discuss any aspect of this guidance further or could contribute to a case study on class participation please email the Teaching and Learning Centre (tlc@lse.ac.uk) or contact your Teaching and Learning Centre (TLC) departmental adviser.

Contents

Dimension 1: Practice

Image: LSE TLC Photo Archive

Providing opportunities for practice in the classroom

Unsurprisingly, practice – specifically, the opportunity for students to actually engage with concepts through questions and activities – is important for increasing academic performance. Student performance levels are positively correlated to not only the amount and frequency of practice opportunities but to other attributes as well, such as their degree of alignment to summative assessments, or their distribution across the duration of the course.

How frequently do I provide my students opportunities to practice?

Practice opportunities can take a variety of forms, and the methods which are available to you (and appropriate for the class) may vary with topic, time and other resource constraints.

Such approaches can include frequent practice tests (including examination-like questions), classroom voting, asking students to come up with explanations (which can be more effective in developing student understanding than reading instructional explanations) and presentations (which can be successfully incorporated in even highly abstract mathematical courses).

Do my practice tasks align with the summative assessment tasks of the course?

For practice to be effective in increasing students' achievement in assessments, it must be aligned to the tasks and learning outcomes of the course. Such alignment can usually be gauged by similarity to the content and format of previous examination questions.

Do I distribute my practice opportunities over time?

Distributing practice on a particular topic over time rather than, say, massing it into a single class, increases its effectiveness. Consider returning to past topics later on in the course, or explicitly asking students to relate current topics to previous ones.

What immediate feedback do my students receive?

Reducing the time between practice and feedback has also been shown to further enhance the power of practice tasks. Providing opportunities in class for students to attempt practice tasks, and then get immediate feedback on their attempts, can therefore be a powerful learning tool.

Simple quizzes and class voting activities can allow immediate, if somewhat shallow, feedback to individual answers, while having students provide explanations of their answers allows for deeper feedback, though for less students. Collaborative learning activities provide opportunities for students to receive more detailed feedback (albeit on work produced in small-groups) as well as from their peers.

Dimension 2: Logic Development

Image: LSE TLC Photo Archive

Developing students' higher-order cognitive skills

By developing your students' higher-order thinking skills, you can increase the quality of their class discussions as well as effect changes in their goal orientation (for example,

mastery over performance). Rather than allowing students simply to focus on what is right or wrong, provide opportunities to focus on sense-making and logic within the subject. Communication is pivotal here (students must be ready to communicate and explain their ideas as well as receive feedback on this), as well as critical evaluation.

Do I require my students to use higher-order cognitive skills?

What levels of cognitive activity (e.g. levels of difficulty or complexity) do your class exercises demand of your students? *Low-level* questions may be oriented towards memorisation, recollection and reproduction, or the rote application of specific algorithms or procedures to predefined problems. *High-level* questions require a deeper engagement with such things, requiring students to make connections between previously seen concepts and perhaps identify the relevant ideas or actions themselves (rather than telling them what to do). Using high-level questions to test students' learning encourages students to process at a deeper level and boosts memory retention.

Do I provide opportunities for my students to explain/defend their logic?

Having students explain / defend their answers encourages them to focus on sense-making and their logic in class and deepen their understanding of the subject. Studies have shown that this can be a more effective learning strategy than simply reading complete explanations, resulting in better performance in examinations.

To make this particularly effective, students should also be encouraged to explicitly relate their answers to the underlying principles of the task and the methods available to them. For example, "Using the method of substitution to convert the given integral into a simpler one, I shall set…". This principle-based explanation ensures students' thought processes are both explicit and directly related to the concepts covered in the course.

Do I give my students time to think before discussing answers?

Unsurprisingly, explicitly providing time to think about their answer to a question increases the likelihood that students will contribute to subsequent discussion about the question. As well as providing them an opportunity to produce an answer, students can also use the opportunity to produce their own questions and ideas about the topic. Make such opportunities explicit (i.e. tell students you expect them to think about the problem before you will take answers) to signal the importance of thinking (and also to alert them that you will expect student contributions).

Do my students have opportunities to explain their answers to their peers?

Encouraging students to share and explain their answers with their peers can help to deepen their understanding of the material, as well as improve their communication and argumentation skills (particularly in technical subjects). This can be done verbally with paired or small-group work, or in writing, with peer marking exercises.

Working in small-groups is important for transfer problems, i.e. problems that require students to transfer knowledge from one context to another, and has also been seen to increase voluntary contributions from students. The social nature of small-group work can also improve social cohesion and general students' attitudes to discussion topics (particularly in low-performing students who may otherwise be disenfranchised and alienated from the material).

Do my students see problems without hints?

Studies show that hints or suggested paths to correct answers can be counterproductive for students learning. Reducing the effort required of students to get to the correct answer impedes learning outcomes, while sharing 'common answers' may produce the wrong results (in that the common answer or approach is not always the best, or even correct, one).

As well as withholding hints at the start of a new activity, consider how you could phrase questions which requires them to explicitly make connections between the question and their subject material (for example, do not explicitly state the algorithm or method they should use to bring about a solution). This might be particularly useful when using old examination questions for class practice opportunities.

Do my students have opportunities to hear other students describing their logic?

Asking students to put forward explanations not only provides opportunities for immediate feedback (here through peers) but also emphasises that developing logic and critical thinking (and communication) skills are just as important as getting the right answer.

Spoken explanations are not required for this to be beneficial for all students, with peer marking and small-group work providing similar opportunities for developing these skills.

Do my students receive explanations why correct answers are correct and why incorrect answers are incorrect?

In addition to indicating both which answers are correct and which are incorrect, it is also important for students' comprehension that they understand *why* such answers are the way they are (something which is echoed by students). Moreover, openly exploring incorrect answers can further reinforce the portrayal of errors as opportunities for learning.

Dimension 3: Accountability

Motivating and supporting student participation in the classroom

Motivating students to participate is a critical component of the active classroom, but can be hard to foster in service level or particularly abstract courses. Here we focus on the extrinsic motivators which can be less subject-specific, and also more easily identifiable in the classroom.

Perhaps the easiest approach for teachers (both in terms of effort and lack of confrontation) is calling upon volunteers for responses; however, this can easily allow classes to be dominated by a small proportion of the students. Furthermore, if students know they will not be called upon or required to provide answers, they can quickly settle into a pattern of not preparing for classes. How then do we dispel the notion that not all students are expected to participate?

Do I get my students to participate in and contribute to small-group work?

While making contributions in small groups is still somewhat 'voluntary' in nature, such activities can nonetheless lead to an increase in both the quality and the quantity of student answers and discussions. Here, the smaller setting magnifies the perceived responsibility and sense of reward to students for participating, and encourages a stronger sense of social cohesion, further motivating students to participate in and contribute to their small-group. Participation in small groups may also lead to wider participation in the whole class, as students have a chance to try out their ideas in a smaller setting and use peer feedback to refine and develop their logic and thus grow more confident in it.

Do I require all my students to contribute to class discussions?

The simplest method to promote equal levels of contribution from all students is also the most intimidating (for both student and teacher): cold-calling. Dallimore *et al (2012)* discuss how consistently high levels of cold-calling can lead to increases in both the number of students answering questions voluntarily, as well as the number of questions they answer. Cold-calling can also increase students' comfort in participating in class discussions and their preparation for the class. Randomised cold-calling can also be effective in avoiding dominant contributors and eliminating such things as gender bias in participation.

It is possible to make extensive use of cold-calling without making students uncomfortable or see it as punitive. Establish your expectation of student participation early and provide ample opportunity for students to think about the questions (either individually or small-groups) before seeking answers. Consider the level of cognitive demand that your questions are placing on students: use low-level questions (e.g. recollection and simple calculations) early to boost confidence and encourage participation, and gradually moving on to more challenging questions.

Dimension 4: Reducing apprehension

Image: LSE TLC Photo Archive

Addressing the de-motivators of participation

This section discusses how teachers can address the factors which give rise to apprehension or unwillingness in students to participate. Good confirmation behaviours (of teachers) tell students that their contributions are valued and important to the class and therefore encourage participation. Encouraging the adoption of a positive mindset towards error in the classroom can foster a supporting environment in which students feel comfortable to take risks and explore, and perhaps adopt a deeper mastery orientation to their learning (as opposed to a simple performance orientation).

Do I expect and encourage all my students to participate in class?

Focussing on a particular subset of students (e.g. dominant contributors, or simply the ones nearest to the front) can discourage those students who are effectively ignored from participating or contributing to the class.

Activities which explicitly require all students to participate can avoid this bias. Simple methods such as going around the room and eliciting answers from all, or randomised cold-calling can redress imbalances in focus.

Do I give explicit (positive) feedback and encouragement to the entire class (rather than individuals)?

Similarly, only commenting on the efforts of a subset of students will discourage others from making contributions. Communicating positive messages to the entire group can aid in increasing overall participation levels.

Do I recognise and encourage contributions from individuals?

It is also important to note that recognition should be visible to the students – i.e. acknowledging a valuable contribution verbally (e.g. "Good, that's correct." or even "Thank you") leaves more of an impression than, say, simply writing down the response on the board (even if this is intended to indicate it is correct).

Do I frame errors as natural and instructional?

Framing errors as a natural and integral part of the learning process, and not simply as signposts for performance evaluation, can help to reduce students' anxiety about making mistakes. Such framing need not be particularly complex, and even simple statements such as "errors are a positive part of learning and development" and "you can learn from your errors to develop a better understanding of the [topic/activity]" have been shown to have a positive effect on students' attitudes.

A particularly potent message about errors can also come from your own way of handling and embracing them. How do you deal with your own errors in class? How do students perceive your eagerness to take risks, e.g. by addressing previously unseen questions from your students?

Do I emphasize hard work over ability?

A growth mindset towards learning is characterised by a belief that certain traits are dynamic in nature and can be developed over time, whilst a fixed mindset views ability levels as fixed and predetermined. There is strong evidence that shows that fostering the former can encourage students to adopt a mastery orientation to learning, to participate more and in more challenging tasks, leading to better performance in classes. communicating the message that participation is valued in the classroom.

What's next?

This document suggests some basic ideas about different aspects of your teaching that you might want to explore and develop further, through focusing on a particular dimension or individual question. If you would like to discuss any of these in greater depth, you can get in touch with your department's Teaching and Learning Centre adviser.

References

Additional reading

Scott Freeman, Sarah L. Eddy, Miles McDonough, Michelle K. Smith, Nnadozie Okoroafor, Hannah Jordt and Mary Pat Wenderoth (2014) 'Active learning increases student performance in science, engineering, and mathematics.' Proc. Natl. Acad. Sci. U.S.A. 111(23). 8410-8415.

Sarah L. Eddy, Mercedes Converse and Mary Pat Wenderoth (2015) 'PORTAAL: A Classroom Observation Tool Assessing Evidence-Based Teaching Practices for Active Learning in Large Science, Technology, Engineering, and Mathematics Classes.' CBE Life Sciences Education 14(2): 14:ar23.

Bradford S. Bell and Steve W.J. Kozlowski (2008) 'Active learning: Effects of core training design elements on self-regulatory processes, learning, and adaptability.' Journal of Applied Psychology, Vol 93(2), 296-316.

Further reading

'What Not To Do – Practices that should be avoided when implementing active learning.' Carl Weiman Science Education Initiative.