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Column Better than blackboard

The dream course

My last students' evaluations are the highest I can remember: 8.7 on average for the elective course on random graphs and complex networks — my area of research. I am especially happy because this course was very innovative, there was nothing 'normal' about it. There were no lectures, but there was mandatory reading, explorative assignments in Jupiter notebooks, mandatory problem-solving sessions, projects, and alternative grading with explicit emphasis on the quality of writing.

Welcome to the new issue of 'Better than Blackboard'! Today I will write about detailed setup of BSc elective course 'Complex Networks' for Applied Mathematics students at the TU/e. I will tell you about what worked well and what I will change next year. As usually in this series, you can enjoy beautiful illustrations by student artist Mara Chelărescu. Check out more of Mara's art at https://cara.app/vinyllaroll. I am also happy to share that she followed the course as well.

The course context

"Complex Networks" is an elective course in the first quarter of the third year of the BSc Applied Mathematics. Huge credit for designing the course goes to my talented young colleague Mike van Santvoort. Mike couldn't join me in teaching the course this year, so I have involved my PhD student Lorenzo Gregoris.

The course is about random graphs and how they model the properties of real-life networks such as sparsity, number of subgraphs (triangles, stars, cycles, etc.) and community structure. The idea is that students learn how to do complete rigorous mathematical derivations and how to apply their knowledge to real data.

Mike and I developed this course with about 20 students in mind. But eventually we had 40 students: about 20 from math as expected, but also about 20 from Computer Science, two from Data Science and even one chemist. Regardless of the students' background, I decided to stick to strict requirements for writing correct mathematical derivations. After all, it is an elective in mathematics!

The holy grail

Usually, when I teach a course, I ask myself: "If I want the students to properly understand one thing from this course, what would that be?". For this course, my answer was: the second-moment method. It is a powerful technique that is often used in random graphs to prove convergence of empirical average to a constant, in the spirit of the standard laws of large numbers. The mathematical idea of the second-moment method is very simple: the variance of the empirical average must go to zero. But the proof involves technical steps and requires fundamental understanding of the model.

So, the second-moment method became my holy grail for this course. A student can pass only if they can do it and write it down correctly.

Amazing talents in the room

I started the course with an activity inspired by the growth-focused ice breaker of Robert Talbert [2]. It goes as follows. First, ask the students what they are good at. It can be anything, not necessarily related to their study. Then, ask them how they became good at it. Very likely most of them will say 'practice'. And this is a good entry point to tell them why you have mandatory practice during the course (in my case, mandatory reading and Problem Solving sessions). I found 'ice breaker' sounding too corporate, so I called this activity 'Who is in the room?', as per suggestion from ChatGPT (I already mentioned this in my previous article [3]).

At the very first session, I gave each student a blank A4 and asked them write their name and the answers to Robert Talbert's ice breaker:

- What are you good at?
- How have you become good at it?

Then I used a so-called sweeping method from the wonderful book *Uncommon sense teaching* [4]. I asked each student from left to right, from first to the last row, to name one thing they are good at. (I believe sweeping works well for up to plus/minus 40 students. For a larger group, I would have used online quizzing software.)

There was an impressive variety of talents in the room! From cooking and playing guitar to long-distance cycling and even calisthenics. Then I asked students to say how they became good at it, sweeping in the opposite order. The first 7-10

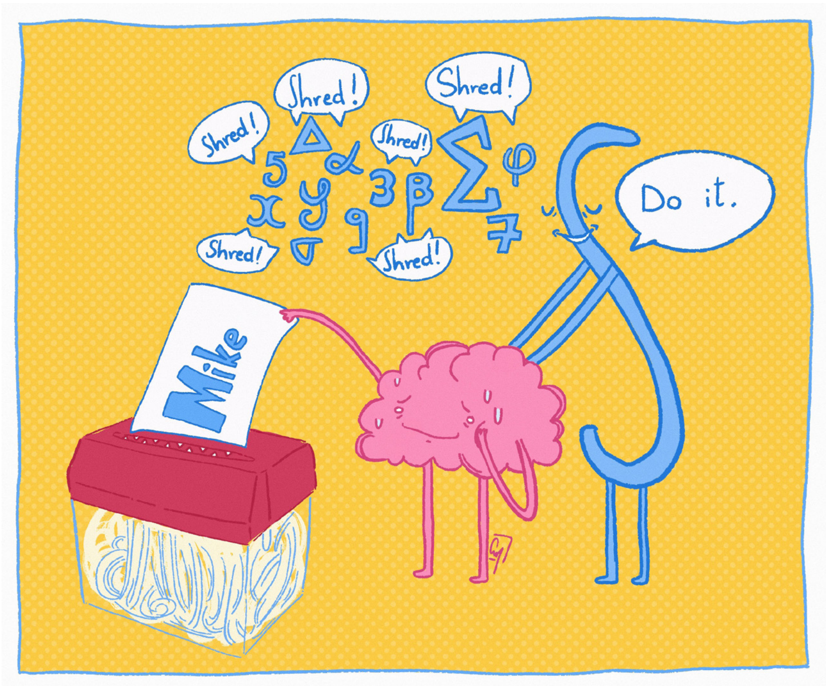

Illustration: Mara Chelărescu

When we learn mathematical formulas, these formulas try to occupy the same circuits in our brain that are destined to faces and places.

students answered: “Practice”. I stopped sweeping and asked: “Does anybody has anything else but practice?”. To be fair, one student said: “I am very talented”, but even this student admitted they had to practice.

As intended, this activity gave me an entry to explaining why I assign mandatory reading and hold mandatory on-campus Problem Solving sessions.

However, there was another effect that, in the end, I find even more important. I was genuinely amazed how interesting and talented my students are! I have collected the papers and reviewed them several times during the course. I noticed how it helped me to see students as mature and inspiring individuals rather than an abstract audience.

I know some institutions ask students to make a slide about themselves and then share the deck of such slides with every teacher. I believe this is great practice! I generally love students. But I vividly experienced that knowing more about them substantiated my respect for them on a whole new level.

Knowing students by name

At the first session, I also asked students to make name tents. For that I gave them one more blank A4 sheet and passed around a couple of markers so that the names were clearly visible.

I was determined to know all students by name. Problem is: I am terrible at it! I’ve read in the book *How we learn: The new science of education and the brain* that when we learn mathematical formulas, these formulas try to occupy the same circuits in our brain that are dedicated to faces and places; maybe that’s why the stories of absent-minded mathematicians might ring true. I strongly suspect this happened to me! Or maybe I was born with a terrible visual memory. The only thing I do more often than getting lost, is introducing myself to people I already know. But I used the name tents before, in a smaller course, and I hoped that — with some effort — the same method would work again.

During the first class I looked at the name tents and addressed students by name. After that I remembered a couple of them: those who looked different and those who talked most. Importantly, I collected the name tents and took them with me. Next time I gave the name tents to the students that I remembered and made some failed attempts with the rest. They corrected my errors, and we made fun of it altogether. Then I collected the name tents again, and so on. By the end of week 3, I knew all names. Nailed it!

It made a huge difference that I knew the students by name. They didn’t say anything specific about it in evaluations, so I don’t have any evidence that students felt a difference. But surely, I did. Interaction with the students was very natural, meaningful and enjoyable when I knew them by names like there were my colleagues. This was priceless, because interacting with the students is exactly what drew me into this profession in the first place. It was also easier for me to expect and maintain attendance when I knew all students personally. I know that learning many names in a short time is difficult; it was difficult for me as well. But I do believe it is worth the effort and I will do it again next year.

Mandatory attendance

Lately, and especially after covid, attendance on-campus has been outrageously low. But I knew that in a technical elective course like mine, most students cannot succeed by learning from solutions. They must solve problems, struggle, discuss with each other and with me. And for that, they must be in class! I had no intention grading sloppy exams of students whom I never saw before. So, in the official course description I checked the ‘mandatory attendance’ box.

Already during the summer the e-mails had started dropping in whether attendance would indeed be mandatory. Students had all sorts of reasons for absence, from work to long distance travel. I answered that not all classes would be mandatory, but that some will be.

At the end, the only mandatory class was the Problem Solving session, only 3 times during the course! For this session, I divided students into two groups: 13:30-15:15 and 15:30-17:15. Turned out, many students couldn’t make it at 15:30. Some had other courses, some lived far away and had plans in the evening, some just had sports activities. I was surprised that it was not an exception. Half of the students had something else in the officially scheduled class time! I tried to accommodate their wishes and ended up populating the entire 13:30 group with students who could not make 15:30. It worked out, but I found it a telling experience.

I also had in-class Quizzes, four times during the course. Quizzes were not mandatory, but they counted for the grade (I will explain about Quizzes and grades further on), and were therefore very well attended without extra effort from my side.

There were a couple of students who insisted that they were interested in the

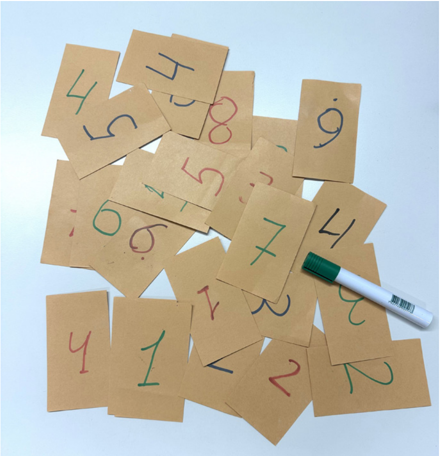

Figure 1 The cards for dividing students into random groups of three.

course, but couldn't attend at all. For the Problem Solving session, I had an assignment to make up for it, and the Quizzes could be done at the exam as well. Yet, unsurprisingly, students who didn't show up quickly stopped submitting assignments and eventually dropped the course. I believe it is a fair process, and dropout is better than ghost students who materialize only at the exam, with usually disappointing results.

Course structure in three modules

It's time to explain the course set up.

The first week was introductory. Students familiarized themselves with most basic mathematical notions and notations and learned how to work with real-life network data. After that, we had three modules of material. Each module lasted two weeks and had the same structure of four sessions.

Session 1: Explorative Jupyter Notebooks. For each module, Mike van Santvoort created Jupyter Notebooks, so that the students could visually and intuitively explore the topics before they learn the proper math. Students could do this in class or in their own time, individually or together. I didn't check this work and there was no grade because part of the code would be used in projects anyway.

Some students said that this initial visual intuition from the notebooks was very helpful. Others said that they preferred to study math first and intuition second. They of course all had freedom to do so; next year I will communicate this more explicitly. Finally, some students didn't do the notebooks, which was not a problem because they did a Project afterwards.

Altogether, I believe notebooks were useful and fun entrance to the topics. Developing such notebooks takes time, but it is quite doable, especially with the help of a talented PhD candidate or AI.

Session 2: Interactive textbook, check understanding questions & short in-class summary. Our main study material was an interactive textbook [1], which we made available in the Feedback Fruits environment within LMS (in my case, Canvas). The book is divided into concise subsections. At the end of each subsection, we have Check Understanding questions, final answer or multiple choice, that students must answer while reading.

Intentionally, *Check Understanding* questions were much simpler than typical exam questions; for instance, applying a formula in a small example or verifying a definition. The idea is that students come back to the text and consciously use the notions and the formulas instead of just gliding over them. I required the students to answer 80% of Check Understanding questions, regardless of whether the answers are correct or not.

Reading in Feedback Fruits must be done online and students quickly told me that this was not always convenient. Therefore, I also provided a complete pdf version of the textbook without the answers to the Check Understanding questions. That seemed to work well. I checked this assignment in Feedback Fruits and registered Pass in Canvas.

Students appreciated the textbook and successfully learned the entire material from it. They also took it seriously. During the course, one of the students said: "It was great that we had mandatory reading. Otherwise, I wouldn't read it".

Students could do the reading in their time, but we also scheduled reading time in class. During that time, I used about 30 minutes to give a very global overview of the module: motivation, scope, main mathematical techniques/challenges. Students found this useful, but to be honest, only half of them was there, so I was happy that, for sure, all of them had to read the textbook.

Session 3: Problem Solving. This was my favorite part! And students liked it, too. In these sessions, students worked together on the Target Understanding questions, which we included in the textbook at the end of each chapter.

I organized these sessions using the '*Thinking Classroom*' method by Peter Liljedahl [5]. In '*Thinking Classroom*' students work in random groups of three on an erasable vertical surface. The groups must be visibly random, so I made it very analogue. Together with a handy colleague, we made cards of thick cardboard and wrote a group number on each card: three cards with number 1, three with number 2 etc (see Figure 1). I had two sessions of 1,5 hour, and maximal 24 students per session, so maximally 8 groups of three.

An 'erasable vertical surface' is just a whiteboard or a blackboard. Almost no room has enough of those for 8 groups, so I bought static writing whiteboard sheets (see Figure 2). This was a tip from Jeroen Spandaw and Bart van den Dries, who already used *Thinking Classroom* at TU Delft; see Bart's article about it on the MathEdN.nl website [9]. Luckily, I've got a room with many glass walls, so there was no risk of students damaging the walls by accidentally writing on them. When students entered the room, they took their number and went to their board. Each group had one marker. Once everyone was at the boards, I explained the problem, and the students started working on it. The session was 90 minutes with a break and usually we could solve two problems.

Mostly, students worked very well. Especially the first, say, 20 minutes were very lively and productive. There were also two challenges. First, there was a big difference between the students who did the reading before Problem Solving and those

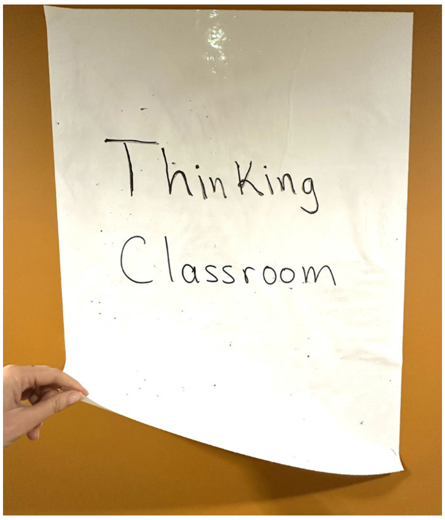

Figure 2 Static whiteboard sheet 60X80 cm. Sticks to any wall and removed without trace. One can write with whiteboard markers and erase with paper tissue. The sheet on the photo has been reused many times :)

Problem Solving. Working on a whiteboard in groups of three.

Illustration: Mara Chelărescu

who didn't. The latter had no clue how to approach the problem. They soon realized this and mostly did the reading; but if they didn't, Problem Solving was not as useful for them and they couldn't contribute to the group. Second, after about 20 minutes, some groups are done and others are stuck. Ideally, in *Thinking Classroom*, students should go talk to other groups. But they don't, they almost see it as cheating. Instead, each group wants feedback from the instructor. Bart and Jeroen warned me about this challenge beforehand. They addressed it by explicitly asking students to join other groups. I tried some version of it, but I don't think I did a great job on this.

I will think next year how to address the challenges, but I will surely use *Thinking Classroom* again. I was a joy seeing the students working together and helping them along.

The attendance of *Problem Solving* was mandatory. If a student missed it, they had to submit solutions to two other problems from the textbook. I didn't give feedback on these submissions, I just checked that the work was done honestly and marked them as done. Usually, 3-5 students submitted assignments. In the feedback, most students said that Problem Solving sessions were very useful. I hope this was the reason why most students didn't skip them.

Session 4: Module Quizzes. There was an online in-class Quiz for each module. Students were doing Quizzes on their laptops. Since there were not many students, we didn't use any protected online environment; instead, one of the instructors was standing at the back watching students' screens. Each quiz had 3-4 (sub-)questions and lasted 50 minutes. Usually, there was one multiple-choice question on understanding the theory, one numerical question for applying formulas, and one open question with longer computations or proof.

I used alternative grading (see the highly recommended book [7] and my previous column [8]). So, we gave a word-grades: "Needs improvement", "Sufficient" or "Excellent". When grading, I used my favorite principle "High standards — high support". High standards meant that I was very strict on the open question. One may say, open question had a weight of 70%, and for "Sufficient", the solution had to at least contain essential correct steps and arrive to a reasonable final answer. For "Excellent", I allowed one minor error. "Excellent" meant excellent, I was very literal about it. One student — when disappointed with "Sufficient" — pointed out that their answers were almost correct. I said: "Look at it objectively. Do you believe it is excellent work?" The answer was an understanding "no".

With these high standards, at the very first Quiz on Module 1, out of 38 students, three had "Excellent", seven "Sufficient" and the rest "Needs Improvement".

It was easy for me to give students a 'failing' grade because there were no negative consequences; I allowed "revisions without penalty", which is a crucial part of alternative grading. Here is how it worked. I gave a Quiz on Module 1 at the end of this module, in week 3. At the end of Module 2, in week 5, I gave Quizzes on Modules 1 and 2. At the end of Module 3, in week 7, there were Quizzes on Modules 2 and 3. In week 8 I gave Quizzes on all three modules. And I did the same at the exam and the resit. Of course, there were new problems for each module in each Quiz. The best result counted for the grade, and the final grade depended on the number of "Sufficient" and "Excellent" (more on the grade below). This system gives students a room to fail safely, and this is fair because failing is a necessary part of learning.

I explained to the students many times that "Needs Improvement" is not failing. They just started learning, so it is only natural that they need improvement at that point. Admittedly, this is hard to communicate, because students grew up in the system where each error is a failure. I was happy when at the end one student said: "Now I understand that in this course, 'Needs Improvement' means literally what it says: that I need to improve." This is exactly the attitude that I want from students, and I will keep working on it.

At home: Projects. Each module ended with a Project related to the content of each module, where students applied and generalized the theory to real-life networks. Students did Project in pairs.

I noticed in recent years that forming project groups or pairs increasingly becomes a problem. If students team up with their friends, they have the same work distribution for each project; for instance, one person always searches the literature and the other one always codes. Plus, some students don't have friends in this course, and I feel that today's students fall out of habit of making friends in class. This problem is real. One student seriously asked me: "How can I find a partner? I don't know anyone here!". My answer was of course that they will meet others; for instance, they will work together at Problem Solving. Yet, even receiving such a question is puzzling and worrisome to me. On the other hand, if the teacher forms pairs, then e-mails start storming in about project partners not responding.

At the first class, I tried out to co-create rules with the students on how to create project pairs. Together we arrived at the rule: self-formed pairs, but different partners for each project. I believe in co-creation, but I cannot say it worked great. Students followed the rule, but I did not feel that they owned it. In evaluations one student wrote that "the teachers didn't know themselves what rules to use".

The Project submission was an executable Jupyter Notebook with comments, and no report. Deadline was one week after the module was finished. Students received feedback on the Project. If they were not satisfied with the result, they could submit a revised version before the exam.

Each project contained about 12 specific problems, and we used a grading system that the book [10] calls 'contract grading': we gave "Sufficient" if at least 75% of the problems were complete, and "Excellent" when all problems were complete. The reason was that students had to work hard to solve 12 problems, and the grade reflected this hard work. At the end, we found this a difficult grading style, because is doesn't account for the quality of the solution. Some students offered original and thought-through solutions, while others did the bare minimum, and yet the problem was complete. Next year we will most likely make a distinction between solutions of different quality.

The final number grade

At the end of the course, students had six 'word' grades: for three Quizzes and three Projects. We gave the final grade based on the number of "Sufficient" and "Excellent". Here are our grade requirements:

Grade 6: 6 × "Sufficient"
Grade 7: 1 × "Excellent", 5 × "Sufficient"
Grade 7,5: 2 × "Excellent", 4 × "Sufficient"
Grade 8: 3 × "Excellent", 3 × "Sufficient"
Grade 9: 4 × "Excellent", 2 × "Sufficient"
Grade 10: 5 × "Excellent", 1 × "Sufficient"

Besides, we had a conversion rule for Module 3. Students may opt-out of either Quiz or Project of Module 3. The skipped activity had to be compensated by "Excellent" in any other Quiz or Project. The conversion rule is: [1× "Opted-out" + 1×"Excellent"]= [2×"Sufficient"]. After conversion, the same grade calculations apply as above.

We didn't require to participate in the exam if students scored "Sufficient" or "Excellent" for each module Quiz during the course. This way, most students finished the course before the exam, and they really appreciated this. I also found it a fair reward for their hard work and growth during the course. It might be different for other courses. For example, Noela Müller and I had an exam requirement in a large 1-st year BSc course [8]. But for this elective course I felt no need for a stressful final exam beyond merely offering an extra chance for the missing Quizzes.

We allowed to redo the Quiz and revise the Project to improve from "Sufficient" to "Excellent". Many students did this, and grades were high; most students had grade 8 or higher. At the end, one student said: "In this course, if you work hard, you will get a high grade. They say it in other courses as well, but this is not always true. I had courses that I liked very much and worked very hard, but didn't get a high grade because I was unlucky at the exam." Students in control of their grade is one of the ideas of alternative grading, and it did work out as intended.

Too high grades?

I believe the students deserved their higher grades, because they did master mathematical content of all three modules and successfully executed the Projects. This requires a lot of work and growth and deserves a reward.

That said, there were also students who aced each Quiz in the first attempt. Not that they were bored, but they did tell me that the course contained less material than they are used to and they could use more challenge and learn more content. Next year I will probably include some optional modules as extra requirement for 9 or 10. It will offer a challenge to fast learners while not stressing out the rest of the students. I am a little hesitant, because making Quizzes for advanced material is not easy. I might assess these modules differently, maybe an oral exam? I am not sure yet.

Steppingstones to the holy grail

I often get the question: "Your course sounds great, but should we all do it in this way?" My answer, time and again: "No". There are millions of ways to set up a great course. I am very happy with this course! But in the essence, I believe, several principles worked for me, and all of them can be implemented differently, whatever fits your style:

- Knowing students by name and knowing something about them made a big difference for me. I did it with the quick ice breaker and name tents. But many other ways, like one-on-one conversations, would work equally well.
- It was important that students were accountable for the mandatory reading. My message was very clear: "I want you to read it and I mean it". We used an interactive document with Check Understanding questions, but it can be done differently. I prefer a mandatory assignment with no grade because I want to make safe room for error. Even a tiny grade loss feels like punishment, and I don't want this while the course is still running and the students are still learning. If I give grades, I want to give opportunity for revision without penalty, and this is too much for a reading assignment. Feel free to disagree.
- I believe it is helpful to divide the questions into two categories: basic and target. Basic questions are very useful for a quick check and conscious start. Target questions exhibit the level expected at the exam. Our textbook explicitly marks the questions as Check Understanding and Target Understanding. But any other form of division will work as well.
- Alternative grading worked like magic. It was humane for the students because failing is a part of learning and they had an opportunity to fail safely. It was also liberating for me, because I could be very strict in my grading. My "Sufficient" was never "almost sufficient", it always meant that the student understood the topic. Whether you use word grading or number grading, revisions without penalty are easy to implement, and they will probably have the same effect.

I am very happy about students' enthusiasm about the topic, their positive feedback, and their smiles when I bump into them in a corridor now that the course is over. My holy grail worked out as well. Every one of 40 students could do the two-pages computations of the second-moment method. This was truly a dream course for me! And this is probably the true holy grail for every teacher.

List of references on p. 63