My Flipped Classroom
What I did and how I did it

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Introduction
In this chapter I describe my own personal experiences with the flipped classroom approach (e.g. lectures at home, problem solving in class) called peer instruction. I have taught chemistry courses since 1996 both in the USA and in Denmark. I used the standard lecture model (always blackboard, never Powerpoint) until about 3 years ago when I switched to peer instruction. So I have a pretty "conservative" teaching background – perhaps much like yours?

This chapter is an abridged, out-of-date, and non-interactive version of my web e-book *Active Learning: Tools and Tips* (Jensen 2014a) where you can find much more practical information and instructional videos. It depicts the approach I take in my second year thermodynamics course (Jensen 2014b).

Learning outcomes and assessment
I teach or co-teach several courses and I use peer instruction in all of them. Here I'll describe the course that I taught most recently: Physical Chemistry for Biochemists. The bachelor course is a required 7.5 ECTS course for biochemistry students (ca 100) who take it in blok 1 of their second year. At the Faculty of Science the teaching year is divided into four 9-week bloks and the normal load is 2 courses per blok. There are 7 weeks of instruction plus one week preparing for the exam ("læseuge"). I teach the first 4 weeks.

The grade is based entirely on a written on a 4 hour written final exam with 20 multiple choice questions. They can bring anything to the exam (books, computer, notes, etc) but they are not allowed to access the internet to avoid cheating.

There are two 90-minute "lecture" periods per week plus one 4 hour problem solving session in teams of up to 30 students, where a teaching assistant (typically a PhD student) is there to answer questions.

The aims of the course are that the students can perform both qualitative and quantitative predictions and interpretations of data from typical thermodynamic and kinetic experiments.

Preparing teaching
How I designed the curriculum
I started by writing the homework problems I really wanted them to be able to solve. They are encouraged to use MAPLE, so the problems can be quite mathematically involved. Ideally they involve some application, experimental data, or simulation. Then I wrote the in-class questions related to the underlying concepts behind the homework problems. I also included some questions on *estimating* answers to questions

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that where similar to the homework questions. Next I created the Powerpoint slides for the videos, containing the information they would need to do the homework, and I recorded the videos. Finally, I wrote the reading quizzes.

Contrast this approach to the usual curriculum "design" in which you find a textbook and select relevant chapters, then divide "number of chapters" by "number of lectures" to obtain content of each lecture, and then hunt through problems in the back of chapters for homework problems, most of which are uninteresting "toy" problems written to illustrate some concept from the chapter. I did this myself for many, many years for the simple reason that all the courses I ever took were designed this way and it never occurred to me to approach it any other way. Also, virtually any discussion I have had with colleagues about new courses have started with the question of what textbook to use and how much of it to cover.

The main problem with this approach is, in my opinion, that most textbooks are pretty awful tools for learning. They contain way too much information (just look at the size of them!) and do a poor job of differentiating important topic from less important information. Also, most are textbook cases (pun intended) of the "just in case" approach to teaching: you need to understand this stuff "for later", which is not a great motivator. Finally, they mostly pretend the world wide web does not exist: all the information you need to know about this topic can (and should!) be found between the copies of this paper book. Is that really the message we want to send to people in the 21st century? Textbooks are *no*t written and published with the students in mind. The "customer" is the teacher who chooses the book, not the student, and the aim of the publisher is to sell as many books as possible at as high a price as possible – period.

Designing and recording videos

Video lectures is by far the fastest way to make your own "textbook" because formulating something in writing is much slower than recording what you are saying. Once you have the slides and a little experience, recording a 7-minute video lecture takes about 7 minutes.

You can see some examples of video lectures that I made at (Jensen 2014b). The two videos above nicely illustrate how I do it: you simply go through your Powerpoint presentation of your computer and Screenflow records what's happening on the screen and what you say. Then, usually after a bit of editing, I upload the video to my Youtube account.

Good video lectures should have these features:
- The optimal length is about 6 minutes (Guo 2013)
- One specific topic per video (remember you only gave 6 minutes)
- At least one multiple choice question per video (to test comprehension)
- No more than 7 such videos (new topics) per lecture period. (See Wieman 2007 on cognitive load)

Some practical tips

* Once you start a recording, don't stop. If you make a mistake, keep quiet for a moment and start that part over. You can fix the mistake by editing and the quiet moment allows you to cut without interrupting the narration.

* Keep quiet for a second before and after changing slides. This allows you fix errors on a particular slide without affecting other slides.

* Once you finish recording a video your first instinct will be to delete it. Try waiting a day and listening to it again. I bet you'll feel better about it.

Writing good peer instruction questions

A good peer instruction question is a question that facilitates a good discussion and is just difficult enough that about half the students get it wrong on the first vote. Such questions are hard to write. Be prepared to spend time and mental effort on this, and to revise or replace questions in coming years as you get feedback from the students. If you ask bad questions students will grow bored quickly. Avoid simple recall questions (the particles orbiting the atomic nucleus are called ...?), questions that can be answered by a simple Google query, or questions that require a calculator (how many moles in 32 g of Bi?), none of which facilitates discussion. Some examples are shown in Figure 1

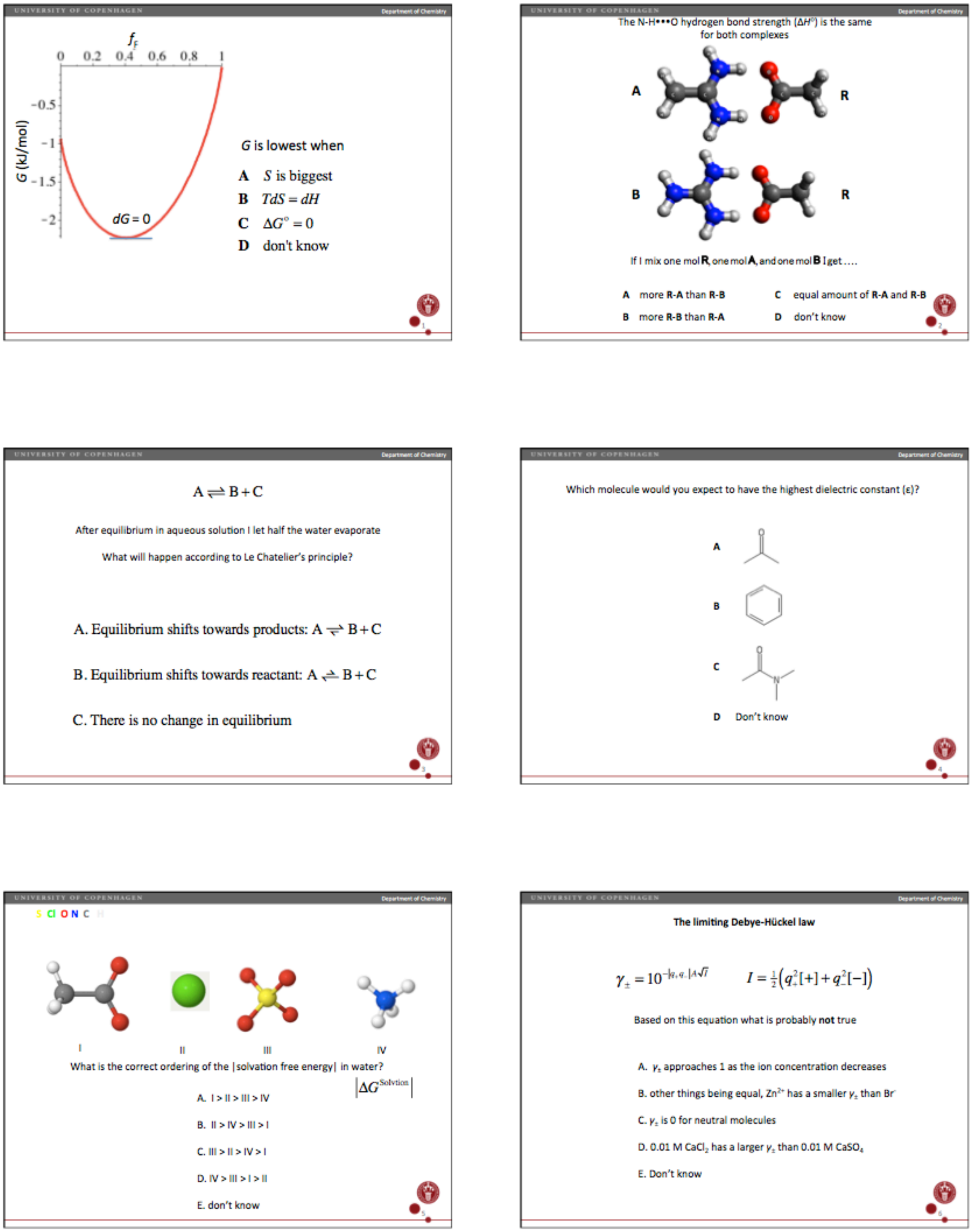

Figure 1. Some example of clicker questions I have used in my thermodynamics class.

Slide 1. This is a typical multiple choice question where the students are presented with several answers that are quite different from one another. These are hard to write because it is difficult to come up with several different but plausible answers (see also slide 6).

I use this question to address two common mistakes I have seen my students make: *A* looks good because they confuse the entropy of the universe (which goes to a maximum according to the second law) with the entropy of the system. *C* looks good because students confuse the *standard* free energy change with the free energy of the system. I also use graphs and pictures whenever possible.

Slide 2. A better approach is often to formulate questions such that the possible answers are "more", "less" or "the same" (or "increase", "decrease", "stay unchanged"). This is probably the most used peer instruction question format. The challenge then is to formulate the question such that one of the wrong answers looks most plausible. Here the two complexes look very similar, so option C is somewhat attractive.

Slide 3. Another variant of more/less/the same.

Slide 4. Another approach is to ask which X has the largest/smallest value of Y. Here it is important that the choices are sufficiently different so that the answer can be obtained without looking anything up or memorizing it. In this case each molecule has a different number of polar atoms. The question can also be rewritten as a ranking problem, such as that shown in the next slide.

Slide 5. Ranking in order of increasing/decreasing X. I use molecular models rather than chemical formulas so that they have to deduce the molecular charge themselves and get a sense of the relative size of the molecules; both if which are key to answering the question correctly.

Slide 6. This is an example of how to cover equations without asking questions that require a calculator. Also, since it harder to formulate plausible wrong questions I ask for the answer that is not correct (see Peter Brunbech's chapter in this book).

Experiments and simulations

The above type of questions can be greatly improved by including (movies of) experiments or simulations. It makes the topic less abstract and more relevant and it addresses exactly what chemistry is all about: explaining observations in terms of the behavior of atoms and molecules.

I typically search Youtube for "xxx experiment" or "xxx simulation" and then capture the part of the video I want with screencasting software such as Screenflow or Camtasia and insert the resulting movie in a Powerpoint slide. Of course you can perform the experiment in class or record your own experiments in lab.

You can see some examples in this video (Jensen 2014c)

In my options for answers I always include a "don't know" option and instruct: "If you really have no idea how to attack the problem, don't guess; let me know by voting "don't know".

Another advice on designing questions is that the teacher should not over-define the

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problem. It's OK to leave things out (such as underlying assumptions or simplifications) and let them ask you as needed.

Student preparation for teaching: Quizzes and problems

Quizzes

A basic tenet of the flipped classroom approach is that students come prepared to class and I have found "reading" quizzes good way to help ensure that. (Here I put reading in quotation marks since it can also refer to video lectures.) Put another (stronger) way, I would not attempt any kind of flipped classroom activity without assigning reading quizzes. My reading quizzes are usually 5-10 questions covering reading/video material the students familiarise themselves with before we meet. If you require more questions to cover the assigned reading/video then you are assigning too much. The quiz has two purposes: 1) to encourage students do the reading/watch the videos and 2) to let them know whether they have watched them with sufficient attention.

I use the quiz function in Absalon, which is the course management system that the University of Copenhagen uses, but I am sure most of what I discuss below can be done with other course management systems such as Blackboard of Moodle.
Absalon allows me to label the quiz as "mandatory", though the repercussions for not taking it is left vague.
The quizzes are not meant to be extra homework. The questions are easy to answer if you have read the material. I often use true/false questions. I allow (and ask) students to keep answering until they get all the questions right.

The last question is always "Did you find anything confusing that you would like explained when we meet?" I set the deadline for the quiz at midnight the night before we meet. There is good evidence that sleep is important for the transfer of knowledge from short- to long-term memory. Absalon has a useful feature where I can selectively send email to students who haven't taken the quiz yet. If I remember, I do this around 8 pm. The homework does not contribute to the grade (which allows me to give immediate feedback). *This is really important as it turns the quiz into a learning tool*. However, PeerWise uses points and badges as motivators (Denny 2013), and I frequently highlight the numbers and kinds of earned badges on the course website.

Homework problems

Teams of up to 30 students meets with a teaching assistant for a 4 hour session every week where they can get help with the homework. If possible I show up for an hour or so for each session to get a feel for what students are struggling with. How else will you know?

Each week I present them with about 10 homework problems, of which they have to solve a minimum of about six. The first six are relatively easy and should be doable by everyone who deserves to pass. The last four are more challenging and one of them is typically an open ended question. The mere fact that the student chose a particular problem makes the student invested in solving the problem. In my experience most students attempt all 10.

Carrying out teaching

The "lecture"

I meet with the students twice a week for 90 minutes (plus a 15 min break in the middle). The very first time we meet, I lecture for 5-10 minutes, then ask a question on which we vote using Socrative.com, and repeat.

Before every meeting after the first session the students must watch 4-6 video lectures, each 5-10 minutes long. Each video concludes with a multiple-choice quiz question with an answer, i.e. immediate feedback. The videos are based on PowerPoint slides that the students have access to while they watch the video. The students get the Powerpoint slides with the questions (but not the answers) after our meeting. The Powerpoint slides and videos replace the textbook for the course.

Using quizzes and feedback

The questions are relatively easy to answer (often T/F) for someone who has watched the video. The deadline for the quiz is midnight before the meeting. The quiz is mandatory, though the repercussions for not taking it is left vague (as soon as you attached points to it students will focus on the points and not use it as a learning tool). The University of Copenhagen course site has a useful feature where I can selectively send email to students who haven't taken the quiz yet. If I remember, I do this around 8 pm. The quizzes do no contribute to the grade, which allows me to give immediate feedback.

During our meetings I use the peer instruction approach (defined below). I ask about 10 multiple choice and 2 short answer questions using Socrative. Roughly half the questions cover material from previous weeks and new material, respectively. The questions tend to be conceptual questions that facilitate discussion. The answer to the question is provided as multiple choice using the PeerWise platform (Denny 2014), i.e. the student is presented with 4 possible (often numerical) answers, where one is the correct one. After the student chooses one answer he/she is presented with a detailed explanation of how the problem should be solved. In some cases this takes the form of a video, but most often the solution is a screenshot from MAPLE.

Using clickers and peer instruction

Peer instruction is an alternative to the traditional lecture and was pioneered by physics professor Eric Mazur at Harvard (Crouch & Mazur 2001).

The "mechanics" of peer instruction

The teacher poses a (multiple choice) question to the class. The students vote on the answer using clickers or e-clickers. Mazur advocates that students not be allowed to discuss before the first vote. I encourage students to discuss right away. I admit I have no scientific reason for doing this. I just can bring myself to tell student they can't discuss the problem.

If the majority (roughly >75%) vote correctly, I briefly explain the correct answer and move on to the next question. If 40-75% vote correctly, I ask the student to find someone who has voted different than themselves and convince them that they are right, then re-vote. If <40% answer the question correctly, give a detailed explanation of the problem and solution.

I find that the advantages of peer instruction are that good peer instruction questions focus on conceptual understanding, which is rarely addressed in homework, and certainly that students are doing something active rather than sitting passive. I find that students have an easier time learning from their peers who are at the same "level". Last, the teacher gets valuable feedback on what the students know and don't know.

Assessing what is learned

With the Peer Instruction approach I assess what is learned during every "lecture" period. This allows me to write much better exam questions: it is fairly easy to formulate questions with a range of difficulty and I now rarely write exam questions that no-one can answer. My goal is to write peer instruction questions that ca 50% can answer on the first try and my first attempts at questions are often too easy, indicating that they retain quite a bit from the video lectures. It is very clear from the feedback that concepts need to be repeated at least three times over a period of weeks before the students can consistently can answer correct.

In general I have not noticed any significant change in the number of students who pass the exam, but of course the exam questions have changed. I have noticed two things though: (1) the number of students who attempt the exam have increased a little compared to when I lectured (2) students tend to do better on problems involving concepts introduced early in the course (and therefore repeated more often). The opposite was true in the days when I lectured.

Experiences and evaluations

There are a few students who write in the student evaluations that they miss a textbook or prefer lecturing. But the majority of students say that they like the approach and some like it so much they come up and tell me in person. When I started with peer instruction the most common complaint was that it was "too slow". I have made efforts to speed things up a bit by winding the discussion down after ca 60% have voted and spending less time on explanations where >75% answered correctly on the first try. However, I think the main problem was that initially many of questions did not facilitate good discussions, either by being to easy, too focused on simple recall, too quantitative, or on less relevant (to the students) topics. This complaint has now largely disappeared.

It is worth remembering that (1) the flipped classroom approach means more work for the students compared to lecture and (2) that making good videos and peer instruction questions is a skill that, like anything else, has to be learned by doing.

Pedagogical principles underpinning my flipped classroom

Considerations that went in to the curriculum design are the following:

* *"Relevance"* is a great motivator (Bernard 2010, Kenny 2010). Write relevant homework problems and let them drive the curriculum. If something doesn't contribute to

solving a problem, leave it out.
* *"Just in time" instead of "just in case"* (Peeters). Introduce new concepts and techniques as you need them to solve a problem. "You'll need this for later" is not a good motivator in and of itself. For example, spending a lot of time deriving an equation before you know how to use it is not very motivating.
* *Cognitive load.* You can handle no more than 7 new concepts at a time (Wieman 2007). So, one new concept per video and no more than seven videos before each meeting. Yes, you'll have to reduce your curriculum to avoid drowning out the important stuff.
* *Spaced repetition.* Things don't "stick" (committed to long term memory) until you have seen it 3-4 times over a period of weeks (Nickson). Covering something once or repeating something several times in the same lecture doesn't work. This means you have to start the course with the most important concepts to you can repeat the most important stuff most often. Yes, you'll have to reduce your curriculum since you have to cover many concepts several times.

Considerations that went in to the choice of teaching style are these:
Active learning. Ultimately, you are teaching students skills not facts. You only learn skills by actively doing something. As you apply the skills often enough you will commit the relevant facts to long-term memory.
Peer instruction. Students have an easier time understanding explanations given by their peers than by you and students learn an awful lot by actively explaining things to their peers.
Formative assessment. Answering questions is a powerful learning technique if you get immediate feedback. Problem solving and conceptual understanding are two different skills and both must be assessed.

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Video lectures vs live lectures
Advantages
* Students can watch video lectures anytime they want (e.g. when they are most alert), and anywhere they want (e.g. on the bus on a smartphone)
* You can pause and repeat part of the lectures.
* You can watch all or some the lectures again and again (e.g. while doing a homework problem or preparing for an exam).
* As a teacher you can't "get behind" on your lecturing.
* Video lectures free up valuable class time for discussion, e.g. using peer instruction.

Disadvantages
* Students cannot ask questions right away – but in most large courses this is practically impossible anyway. In my experience questions occur very infrequently, even in smaller courses.
* If you use your lectures to inspire and motivate students, then that is probably better done live
* While students enjoy such lectures, there is no evidence that they learn more from them than "boring" lectures.

* Students may not watch the videos - but then students may also skip your live lectures.

Video lectures vs assigned reading and lecture notes
If your lectures (or some of them) are basically repetition of the textbook, just assign the reading instead of making the video lectures. Make sure students read textbook material using "reading" quizzes.
Another alternative to making videos are detailed lecture notes, if you have them already. If you don't, making video lectures is much faster than writing detailed lecture notes. In any case, I always give students access to the Powerpoint slides or the handwritten notes I base the video on. It is much faster to read these notes than to watch the video. If the written material is clear, there is no need to view the video.

Powerpoint vs chalk-board (pen-cast) lectures
For live lecturing, students tend to favor chalkboard lectures over Powerpoint lectures, because the pace of chalkboard lectures tends to match that of note-taking. The relatively slower pace of chalkboard lecturing also means that fewer new concepts are introduced during lecture. In the case of video lectures these differences largely disappear. Students can pause and repeat Powerpoint video lectures. Pen-cast lectures (the video equivalent of chalk-board lectures) are no longer restrained by the available lecture time and can cover just as much as Powerpoint lectures. It it telling that it is possible to view Powerpoint video lectures on the on-line platform Coursera at 1.5 or 2 times the regular speed. There seems to be no demand for slowing the Powerpoint lectures down!

I tend to make PowerPoint video lectures rather than pen-casts because I often present rather complicated equations or diagrams that are laborious to write or sketch by hand. However, if I want to demonstrate some thought process (e.g. solving a problem), I use pen-casts.

Software

Screencasts
Almost all my video lectures are **screencasts** of Powerpoint presentations made using the screencasting software Screenflow. Screenflow only works on Macs but there is a very similar program for Windows called Camtasia.

The free program Molecular Workbench also has an extensive library of simulations and allows you to make your own.

There are two main differences between the videos and my approach: One difference is that I use the earphones with microphone that came with my iPhone for a better audio recording. The other difference is that I don't record myself talking with my webcam because I personally find these "talking heads" distracting when I watch such videos.The reason I used Screenflow is that it has very powerful, yet easy-to-use, editing capabilities for fixing mistakes. The same is true for Camtasia and this video gives an example of a correcting a mistake.

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Other uses of screencast
Screencasting in general, and Screenflow and Camtasia in particular, are very versatile tools that can be used for many other things.

For example, I frequently use Screenflow to grab fragments of Youtube videos or simulations to include in my Powerpoint slides. Here are some examples:

A screencast is also an excellent way to show how to use a particular program or website. Here I show how to use a particular feature of the program MAPLE.
* Hosting your videos on Youtube has many advantages such as optimized views for mobile devices and good buffering for slow internet connections. You can control who can access your videos on Youtube, though there is really no good reason not to share the video with everyone.

* However, if you want to host the video in a place not recognized by Screenflow or Camtasia, such as a university server, you can export the movie to a file and upload the file.

Other ways of making pencasts
While the Explain Everything app is cheap investing in an iPad just to make screencasts is relatively expensive. I have also tried to cheaper alternative methods to making pencasts (NB: I haven't used either for a while so this may be outdated):

The Echo Smart Pen. The main advantage of this pen is that it is an actual pen writing on real paper so the writing process will seem more natural. Another advantage is that it produces an animated pdf file that makes it easy to skip or fast forward through the presentation.

The disadvantages are that (1) I found the file management (transfer, upload, etc) very cumbersome and non-intuitive, (2) no way to edit out mistakes (3) no way to import pictures or files, and (4) only one color.

Graphics tablet & pen. In this approach, made famous of Salman Khan, you use such a tablet to write in a graphics program on your computer while recording using screencasting software. While low-end tablets are much cheaper than the iPad, it is much harder to learn to write one place (the tablet) while the text appears another place (the computer screen). I, for one, quickly gave up.

The iPad + Explain Everything app
The pencast is made using an iPad and a $3 app called Explain Everything. In addition I used the headphones/microphone that came with my iPhone (which makes the audio recording a bit better) and a stylus. *Using a good stylus is really key to this approach* and I have good experiences with both the Jot Script and the Jot Pro (I can't quite make up my mind whether the Script was wort the extra money).

There are many other pencasts apps for the iPad but all the other ones I have seen only give you one finite size page, whereas Explain Everhing gives you unlimited number of pages of infinite size (see 2:20 min of the video immediately above. The video at the top of this post uses one infinite size page.

While I usually upload the video to Youtube directly from the app, it is also possible to save the movie file on Dropbox and import it into a video editing program such as Screenflow to edit out mistakes.

Note that you can import pictures, pdf files, and even entire powerpoint presentations into Explain everything to use as part of your pencasts

Flipping your classroom – getting started

Completely flipping your classroom with videos, clicker questions, etc. is a lot of work. One way to make it happen is to do it in stages. It is better to do a little bit than nothing at all.

The alarm clock approach
The most common use of clicker-questions is to give a multiple choice clicker question about half-way through the lecture to wake students up. This begs the question "why put them to sleep in the first place" but it's better than letting them sleep. It also gives you some feedback on how much the students have absorbed.

If you feel you can't even spare 5 minutes for a clicker question because you are always hopelessly behind in the lectures then there is something seriously wrong with the way you teach.

An experiment: Is lecturing necessary?
1. Make a 2-3 question reading quiz on a topic you would like to skip in a lecture and that you feel the book explains well.

2. Give 1-2 in-class clicker questions that, if answered correctly by >75% of the students, will make you comfortable skipping the topic in your lecture.

3. Repeat a very similar in-class question on the same topic next week (yes, you'll need to repeat material to make it stick).

Convinced? Good, now:

The first year
Look through your lecture notes and replace those parts of lectures where you mostly repeat the textbook, with a reading quiz and in-class questions.

The second year
Record video lectures where you deviate from the textbook and use the entire lecture period for questions. This will also free up time for review questions on previously covered topics.

The third year
Rethink the course in light of what you have learned. Is the book helping or hurting the course? Does it cover what you want in the order you want it? If not, consider getting rid of the textbook and replacing it entirely with video lectures. When doing so, consider reducing the curriculum compared to the textbook.

Workload
Clicker questions.
In my experience I get through about 6 good clicker-questions per 45 min period: about 3 review questions and 3 questions on new topics. It's OK to re-use or only slightly modify questions that you haven't used for at least a week (if you don't believe me, try it).

It's hard to write good clicker questions. Be prepared to replace questions that are too easy or too hard the following year.

Reading quizzes. You need to give a reading quiz before every lecture period where you give clicker questions on new material. The reading quiz shouldn't be more than at most 7 easy-to-answer (if you have done the reading or watched the video) questions. I often use true/false. It usually takes me 15-20 minutes to write such a quiz.

Video lectures. The optimum length for a video is about 7 minutes. If you already have lecture notes or Powerpoint slides and are comfortable with the recording software you use then making a 7 minute video takes about 15-30 minutes depending on the amount of editing you do. This does not include the upload to Youtube, which can be up to 30 minutes depending on internet speeds, but you can do other things during that time.

Concluding remarks
While I am fairly happy with my current approach to teaching it probably doesn't go far enough. It is still very teacher driven: *I* choose the curriculum. *I* choose the order. *I* choose the questions, etc. I feel the students would learn more and be more motivated if they drove the learning. I hope someday I will make the effort required to change that. I once read somewhere that the only common trait of "great" teachers is that they are always changing how they teach.

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