Designing and Evaluating a Flipped Signals and Systems Course

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Abstract: Traditional lectures have long been criticised for making students passive listeners instead of active participants. In spite of many strong arguments in favour of active learning most engineering courses are still based on lectures that only contain few elements of active learning. In flipped classroom teaching, traditional lectures are replaced by a combination of 1) on-line videos to be watched at home before the class and 2) classes dedicated almost entirely to active learning. A key advantage with the flipped classroom is that students can engage with the material at their own pace prior to the class such that class time can be dedicated to higher-level cognitive learning. However, even though the flipped classroom has received considerable attention over the past decade there are relatively few studies evaluating this pedagogical method in engineering education.

In this case study, we report on the implementation and evaluation of the flipped classroom approach in a master's course on sensor fusion and nonlinear filtering at Chalmers. The course design was inspired by the 5E model (Bybee et al., 2006) in that we used the videos for engagement, exploration and explanation whereas the classroom sessions focused on elaboration and evaluation. The students' perceptions of the flipped classroom approach were probed through a survey containing both closed and open-ended questions. The vast majority of the students were either positive or very positive to the flipped classroom approach. For instance, 74% of the students strongly agreed with the statement that flipped classroom teaching leads to improved learning, 96 % stated that they preferred video lectures with quizzes to live lectures, and 87 % found the practice sessions useful. As the course contained both traditional lectures and flipped classes, we could compare how the two methods affected students' learning.

From a teacher's perspective, flipping the classroom was both extremely rewarding and very demanding. Flipping the lectures required a significant amount of work, but when the material was developed, teaching was more stimulating and less demanding than in a traditional course. Although it was challenging to design the problems for the practice sessions, these sessions were the most exciting and rewarding parts of the course.

Keywords: flipped classroom teaching, engineering education, video lectures, active learning, peer instruction, collaborative problem solving.

1. Introduction

Engineering education is often criticised for relying too heavily on the traditional lecture method which leaves little room for students to actively engage with and make sense of the material (Felder & Brent, 2003). However, during the past few years, the flipped classroom (Bergmann & Sams, 2012; Lage, Platt & Treglia, 2000; Roehl, Reddy & Shannon, 2013) has generated considerable interest among engineering educators as a promising alternative to traditional lectures. Martin (2011) describes the idea of the flipped classroom in the following way:

> "Flip your instruction so that students watch and listen to your lectures (or those of other expert lecturers [...]) for homework, and then use your precious class-time for what previously, often, was done in homework: tackling difficult problems, working in groups, researching, collaborating, crafting and creating. Classrooms become laboratories or studios, and yet content delivery is preserved."

Students are consequently first exposed to the new material prior to class and focus on deepening their understanding of the material during class, where they can get support and feedback from their teacher and peers. This means that activities involving lower levels of Bloom's taxonomy for the cognitive domain (Krathwohl, 2002) are moved out of class time to make more room for higher level cognitive activities, such as applying, analysing and evaluating. This flipping of in-class activities and out-of-class activities is summarized in Table 1. The fact that "content delivery is preserved" through the on-line videos is probably a key reason why engineering educators have become interested in the flipped classroom.

	Outside class	Inside class
Traditional teaching	Solve problems – after class *Higher-level cognitive activities* Often individual activity	Listen to lectures *Lower-level cognitive activities* Often individual activity
Flipped classroom	Watch lectures – prior to class *Lower-level cognitive activities* Often individual activity	Solve problems *Higher-level cognitive activities* With support from teacher/peers

Table 1: A comparison of traditional teaching and flipped classroom teaching

There are several advantages of the flipped classroom. The videos allow the students to pause, rewind and review the lectures and thus engage with the material at their own pace. The video lectures are often followed by on-line quizzes, allowing the students to test and receive immediate feedback on their understanding of the material (Demazière & Adawi, 2015). The quizzes also allow teachers to continuously monitor the students' understanding of the material and to plan in-class activities accordingly. When lectures are turned into homework, class time can – to a much greater extent – be devoted to active learning or "anything course-related that all students in a class session are called upon to do other than simply watching, listening and taking notes" (Felder, 2009). There is a large body of research demonstrating that active learning strategies can significantly improve student learning and engagement as compared to the traditional lecture method (Deslauriers, Schelew & Wieman, 2011; Freeman et al., 2014; Mazur, 2009; Prince, 2004), which is perhaps the most important argument in favor of flipped classroom teaching.

However, the transition from the traditional lecture method to the flipped classroom method can be challenging for teachers. Gerstein (2015) argues that a major barrier to the implementation of the flipped classroom is that

> "[e]ducators, as a group, know how to do and use the lecture. When educators are asked to replace their in-class lectures with videotaped ones (either their own or others) that learners watch at home, educators may not know what to do with this now void in-class time . . . In other words, the message to teachers to do what they want during classroom is not enough to make this transition."

Disciplinary case studies describing how to implement the flipped classroom approach therefore play an important role in helping teachers to see how the flipped classroom could be implemented in their own discipline. A central aim of this article is, therefore, to illustrate one way of implementing the flipped classroom in engineering education.

Although the flipped classroom has received considerable attention, there are relatively few studies evaluating this pedagogical method in engineering education (Estes, Ingram & Liu, 2014). Moreover, Bishop and Verleger (2013) urge researchers to more clearly describe the philosophical basis for the design of the learning environment and they emphasize the importance of a suitable pedagogical theory:

> "some may [...] conceptualize the flipped classroom based only on the presence (or absence) of computer technology such as video lectures. This would be a mistake, since the pedagogical theory used to design the in-class experience may ultimately be the determining factor in the success (or failure) of the flipped classroom."

For an overview of empirical research on the flipped classroom and relevant theoretical frameworks, see Bishop and Verleger (2013) and Estes, Ingram and Liu (2014).

In this article, we first describe the implementation of the flipped classroom approach in a master's course on sensor fusion and nonlinear filtering at Chalmers University of Technology in Gothenburg, Sweden. We draw on the *5E model* (Bybee et al., 2006) as a theoretical framework to discuss the overall design of the teaching and learning activities in the course. We then turn to the evaluation of this pedagogical approach, addressing three questions:

1. How do the students perceive the flipped classroom approach?
2. Do students reach the learning objectives without traditional lectures?
3. What are the pros and cons of the flipped classroom approach from the teacher's perspective?

Finally, based on our evaluation study, we discuss what to keep and what to change for the next iteration of the course.

2. Course details and design

We made use of flipped classroom teaching in a master's level course when it was taught for the first time during the fall 2014. The name of the course is *Sensor fusion and nonlinear filtering* and it is offered as an eligible course at an engineering program at Chalmers University of Technology. In 2014 we had 35 students in total, among which most were following a master's program called Systems, control and mechatronics. The learning objectives of the course are related to nonlinear estimation in dynamical systems and most of the students had a good background on how dynamical system can be described, but generally a much weaker knowledge on estimation theory and statistics. Since the course is given in the second year of that master's program, the students have typically just started their fifth and final year at the university when they attend the course.

The course does not include a written exam. The students are instead mainly evaluated on how they perform on weekly hand-in assignments, made up of five home assignments and two projects. Students are encouraged to collaborate but have to submit individual solutions. While working on the assignments they are offered at least two hours of in-class consultancy time every week, where roughly half the class participated in 2014. Two days after each deadline, we arrange a session where we discuss the solutions to the assignments in small groups.

The course contains ten lectures among which five were flipped in 2014. The flipped lectures were replaced by a set of videos and in-class activities using different types of active learning techniques. To enable the students to participate actively in the discussions during the practice sessions, it is important that they show up well prepared. In this course, we decided to make it mandatory to watch the videos before coming to class and it was also mandatory to attend the in-class sessions. To provide the students with some flexibility, they were allowed eight "late days" that they could use to watch videos or hand in solutions to some assignment after the deadline. The late days could also be used to miss out on a mandatory session, but anyone who failed to attend an active learning session had to hand in solutions to some problems on the same topic.

Gerstein (2015) pointed out that "for educators, who are used to and use the didactic model, a framework is needed to assist them with the implementation of the flipped classroom." We have found the *5E instructional model* (Bybee et al., 2006) to be useful in this regard. The idea of the 5E model is to align teaching with what we know about how people learn. More specifically, "there is an order of events – termed a learning cycle – that should optimally occur in the process of human learning" (Tanner, 2010). The 5E model consists of five stages: 1) *engagement* – the teacher presents new information that promotes curiosity and elicits prior knowledge; 2) *exploration* – students explore concepts through a short activity; 3) *explanation* – students explain what they have observed and the teacher clarifies (misconceptions) and introduces related concepts; 4) *elaboration* – students apply their knowledge in new contexts; and 5) *evaluation* – students assess their understanding and the teacher evaluates progress. The first two phases were implemented through short on-line video lectures followed by quizzes. Class time was then entirely devoted to the next three phases, where the teacher and peers offered support and feedback. We note that the 5E model provides another important argument for the flipped classroom, as it can be difficult to fit these essential phases into a lecture.

2.1 Video design

Every lecture that we flipped was replaced by approximately one hour of video, divided into five, six or seven shorter videos. The length of the individual videos typically varied between six and thirteen minutes, but some were as long as eighteen minutes. Every video contained at least one quiz, a multi-choice question that the students had to answer to check their understanding of the material. All the videos were screencasts with a voice-over, that is, the videos captured a computer screen and also contained an audio narration. At the beginning of most videos, the students could see the face of a teacher as he was introducing the video; see Figure 1 for an example. Apart from the occasional occurrence of a face, the screen only showed a few slides and at times some handwritten comments, illustrations or derivations.

Figure 1: A screenshot from one of the videos in the course

To present the videos in an appealing manner we made use of an online platform called *scalable learning* (http://www.scalable-learning.com), which gave us access to a number of useful features. For instance, the platform enabled the teachers to collect statistics about where in a video the students tend to pause or rewind. The platform also gave us the possibility to check when and if the students watched the videos, which was an essential feature given that it was mandatory to watch the videos.

2.2 Active learning in class

The main objective with flipped classroom teaching is to dedicate the time in class to active learning. Designing the in-class activities is often challenging simply because there are so many possibilities to be creative and develop strategies that are tailored for your course, your students and the material in a specific lecture. Fortunately, active learning is not a new idea and there are many well-established techniques that you can make use of and adapt to your own class.

We started every session with a discussion in the entire class where we went through the correct answers to the video quizzes and brought up a subset of the questions posted by the students while watching the videos. After these fairly brief initial discussions, the rest of the session was dedicated to active learning in groups by means of 1) *collaborative problem solving* and 2) *peer instruction*. For both of these techniques there is considerable empirical evidence in the literature that indicate their usefulness (Prince, 2004) and we elaborate on how we used them below.

2.2.1 Collaborative problem solving

In our course, collaborative problem solving essentially meant that the students tried to solve problems in groups of three to five students. Though this may sound very similar to a conventional tutorial session, the problems were instead designed to help the students develop a deep understanding of the fundamental concepts (Adawi, Ingerman & Pendrill, 2005; Hewitt, 1983). Rather than having the students perform advanced calculations or derivations, we formulated problems with the intention to stimulate discussion. Examples of the type of problems that they were asked to solve include:

1. Relate a (specific) theoretical result to a concrete example from your daily life and use the example to explain different aspects of the theories.
2. List practical examples of when the presented theories are useful.
3. Solve a sequence of small problems. Illustrate and reflect upon the obtained results.

We normally allowed the students to form the groups themselves and in many cases the differences in prior knowledge and ability to solve problems varied dramatically between the groups. As an attempt to ensure that all groups could solve some part of every problem and that very few groups finished an entire problem too quickly, we tried to formulate several sub-problems that went from simple to difficult.

While the students were discussing the problems, there was at least one teacher walking around the room, participating in the discussions and trying to support the students. We often dedicated between 15 and 30 minutes to each of these problems before we jointly, in the entire class, tried to summarize our conclusions from the exercise.

Designing collaborative problems is generally not trivial, but the challenges that we are facing are similar to many other teaching situations in that we first need to understand what we want the students to learn. Inspired by both *constructive alignment* (Biggs, 1996) and *backward design* (Wiggins & McTighe, 2005), we returned to the learning objectives of the corresponding lecture in order to identify the key topics to discuss during the class. Another tool that we used was to look at the questions asked by the students prior to class to identify topics that the students found difficult. This is the idea behind *Just-in-time-teaching* (Watkins & Mazur, 2010). In the future, we hope to benefit from the experience of teaching the course multiple times, since it can help us to build up knowledge about common misconceptions among students as well as a library of interesting problems to discuss.

2.2.2 Peer instruction

Another popular type of active learning strategy is *peer instruction* (PI), initially developed and promoted by Professor Eric Mazur at Harvard University in the early 1990's (Mazur, 2009). The main idea behind PI is to activate students and inspire to reflection as well as vivid discussions by asking multi-choice questions focused on central concepts. To activate the students, it is recommended to follow a certain procedure:

1. The teacher posts a multi-choice question to the students.
2. Students are given one or two minutes to reflect on the question, in silence, and formulate individual answers.
3. Unless almost all students have the correct answer, they are then asked to discuss the question within their groups. The discussion typically lasts for two to four minutes and should focus on why the different alternatives are correct or incorrect.
4. The students finally report another individual answer and depending on the result, the teacher either wraps up the discussion or given the students a second opportunity to discuss the different alternatives.

Like with the collaborative problem solving, the design of the PI questions is also guided by the learning objectives in the course as well as the learning objectives for the corresponding lecture. It is also not obvious when it is better to make use of PI or collaborative problem solving. However, for some concepts there may be a common misunderstanding that can be conveniently highlighted using PI, whereas other concepts may be illuminated well by, e.g., solving a toy example that touches upon its basic properties. An example of a PI question used in the course is given in Figure 2.

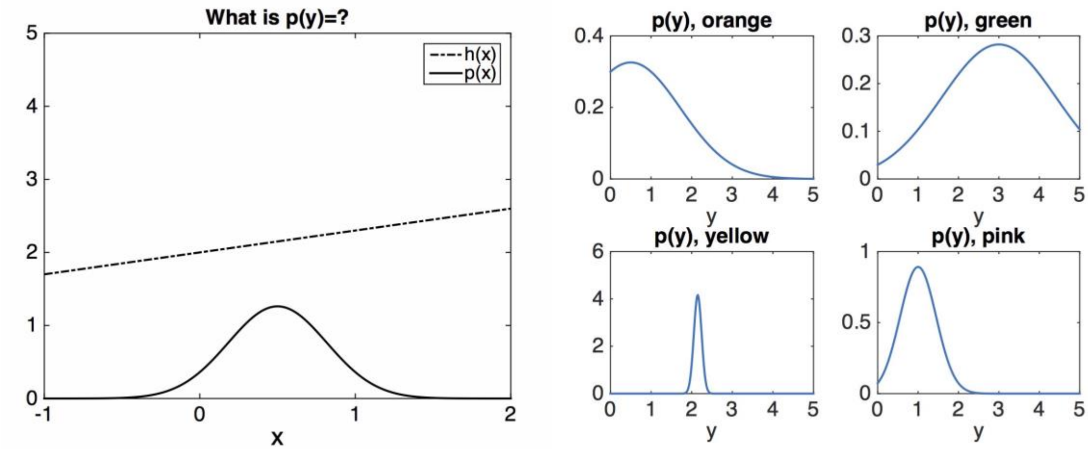

Figure 2: A PI question where students are asked to identify the density of y=h(x). (The correct answer is the yellow alternative.)

3. Course evaluation

We will now return to the research questions presented in the introduction and discuss them in the light of a course survey and a summary of the teachers' reflections.

3.1 Student perceptions

When the course was about to end, all the students were asked to fill out a course survey and 23 students decided to do so. Apart from standard questions, we had included a few additional questions in order to investigate what the students thought about the flipped classroom teaching.

The key results from the quantitative part of the course survey are summarized in Table 2. It is clear that the majority of the students appreciated the flipped classroom teaching model and generally thought that it lead to improved learning. They also liked both the videos and the active learning sessions though not as much as the combination of the two. Considering that existing studies for massive open online courses (MOOCs) indicate that videos should not be longer than six minutes, we found it slightly surprising that the students did not seem to mind videos up to 18 minutes long, see Guo, Kim and Rubin (2014).

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
I would rather watch a video with quizzes than a live lecture	13 (56.5%)	9 (39.1%)	0	1 (4.3%)	0
The length of the videos was good	9 (39.1%)	13 (56.5%)	1 (4.3%)	0	0
Having in-class sessions where we focused on conceptual understanding was useful	15 (65.2%)	5 (21.7%)	1 (4.3%)	1 (4.3%)	1 (4.3%)
The flipped classroom teaching lead to improved learning and better understanding of concepts	17 (73.9%)	4 (17.4%)	2 (8.7%)	0	0

Table 2: A summary of some of the main results in the course survey

In the survey, the students could add comments in connection to each Likert scale question. They were also asked to list the most important things to preserve/change for the next iteration of the course, and what they perceived as the main advantages and disadvantages of the flipped classroom. The comments were consistent with the results from the quantitative part of the survey, and revealed that the students strongly preferred the flipped classroom model to traditional teaching:

- The flipped classroom model is brilliant.
- It's like being forced to read the textbook ahead of class, in a good way.
- Video lectures and practice sessions are tremendously useful for learning.
- I really liked the flipped classroom method. What a difference to other courses.
- The practice sessions combined with the video lectures gave a deeper understanding than ordinary lectures.
- The practice sessions were great and it is really a pity that they got discontinued once we switched to live lectures.
- The structure of the course was very good, and I hope that more courses follow the same structure in the future

The students found it easier to follow a video lecture than a live lecture since they could "stop, think and rewind". Narrated slides and dividing lectures into shorter videos were also highlighted as positive aspects:

- The lectures were easier to follow in video format.
- Being able to watch the lectures at my own speed and being able to pause.
- It's so much easier to understand the material when you can stop, think and rewind. Not to mention the strength of the video-exercise combination.
- [The videos were] very helpful when doing assignments connected to the lectures. It is much easier to understand the slides with the commentary.
- The video lectures give more information than the slides. This is good if you want to review a concept that you didn't understand the first time.
- It was nice that the lectures were divided into shorter videos so that you could take a natural break if you felt like it.

The quizzes were experienced as a valuable tool for self-assessment:

- But also the quizzes were good because then it was easy to see if I really understood the contents of the lecture or if I should study some part of the lecture a bit more.
- With the quizzes in the lectures you know what you understand and what you don't.

The practice sessions were often perceived as the most valuable part of the learning environment. Here, the importance of active- and collaborative learning was highlighted together with opportunities for reflection. The increased interaction with the teacher was also mentioned as a major strength of the flipped classroom. Moreover, the students pointed out the importance of linking out-of-class and in-class activities:

- The practice sessions did much for the understanding.
- The discussions regarding the contents of the lectures were the main advantage I think.
- You become more active and therefore learn things faster.
- It was good to be "forced" to think for yourself and discuss the material with classmates.
- The ability to challenge your own understanding is the greatest advantage in my opinion.
- [It led to] more interaction with the teacher.
- [The teacher] did a very good job in incorporating the feedback form the video in the practice session.

But the students also described what they perceived as negative aspects of the way the flipped classroom was implemented in the course:

- [The video lectures] do not allow you to ask questions and receive answers immediately.
- It is sometimes hard to stay focused all the time when watching, but that is no big difference to having a normal class.
- Videos were good, but some information was only in the videos and not on the slides, which made it harder when you wanted to look something up afterwards.
- Hard to learn from the practice session since the time you need for solving a task is different for each student so either you sit and wait or you are not able to finish before it is time to talk about the task
- The "double" lectures plus assignments increase the workload a lot.

We conclude that the students strongly preferred the flipped classroom approach to traditional teaching and that they believed that it had positive effects on their learning.

3.2 Teacher reflections

To teach a course using the flipped classroom model was a wonderful experience in many ways. Before the course actually started most of our efforts were focused on the development of online material (mainly videos), and it was not until the course started that we fully understood how vastly different active learning is compared to traditional lectures. The students generally show up very well-prepared to these sessions and were eager to learn more, to discuss the material and solve problems. The fact that the teachers spent most of the time in class listening to and discussing with the students gave instant feedback regarding what they had not understood and enabled us to adjust the teaching material according to their needs. Also, since many of the discussions challenged their conceptual understanding of the topic, we frequently observed students who experienced important “revelations” regarding fundamental properties of the studied theories. At an early stage in the course, the new insights that the students obtained were actually often related to fundamental misconceptions based on which very little of the course content would make any sense at all. The fact that the active learning techniques seemed to help the students correct such misunderstandings is itself an important advantage. Overall, it was a pleasure to teach a class where the majority of the students were so focused and seemed to enjoy almost all the time that they spent in the classroom. The main disadvantage that we observed for the teachers was that it is very time consuming to record the videos.

4. Conclusions and future work

In the article, we have described how the flipped classroom teaching model was implemented in an engineering course at master’s level. We have also reported that the students received the flipped classroom teaching style very well. More importantly, both teachers and students experienced a substantial improvement in learning, in particular regarding the conceptual understanding of the material.

It is clear that we should continuously try to improve on both the videos and the in-class activities every time we give the course. One weakness that we would like to address is that the students missed the ability to get immediate answers to their questions while watching the video lectures. We will try to mitigate this by providing a better online discussion forum where students can post questions to their peers and teachers. As for the classroom sessions, students pointed out that some groups were able to solve problems quickly whereas other groups needed more time, which can sometimes make groups either bored or stressed. In the future, the teacher will determine how to divide students into groups (instead of allowing students to form groups at will) in order to reduce these differences.

References

Adawi, T, Ingerman, Å and Pendrill, A-M (2005) How mathematical is conceptual understanding? *Proceedings of Physics Teaching in Engineering Education conference*, PTEE-2005, Brno, Czech Republic.

Bergmann, J. and Sams, A. (2012) *Flip your classroom: Reach every student in every class every day*. International Society for Technology in Education.

Bishop, J. L. and Verleger, M. A. (2013) The flipped classroom: A survey of the research. In ASEE National Conference Proceedings, Atlanta, GA.

Biggs, J. (1996) Enhancing teaching through constructive alignment, *Higher education* 32(3), pp. 347-364.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006) The BSCS 5E instructional model: Origins and effectiveness. Colorado Springs, CO: BSCS.

Demazière, C. and Adawi, T. (2015) The effect of introducing on-line quizzes in a virtual learning environment and implications for the flipped classroom. Paper accepted for the 43rd Annual SEFI Conference, June 29 - July 2, 2015, Orléans, France.

Deslauriers, L., Schelew, E. and Wieman, C. (2011) Improved learning in a large-enrollment physics class. *Science*, 332(6031), pp. 862-864.

Estes. M. D., Ingram, R. and Liu, J. C. (2014) A review of flipped classroom research, practice, and technologies. *International HETL Review*, Volume 4, Article 7.

Felder, R.M. (2009) Active Learning: An Introduction. *ASQ Higher Education Brief*, 2(4), August.

Felder, R. M. and Brent, R. (2003) Learning by doing. *Chemical engineering education*, 37(4), pp. 282-309.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H. and Wenderoth, M. P. (2014) Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 111(23), pp. 8410-8415.

Gerstein, J. (2015) The flipped classroom model: A full picture. Blog entry, accessed 150524.

Guo, P., Kim, J. and Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos, Proceedings of the first ACM conference on Learning @ scale conference.

Hewitt, P. G. (1983) The missing essential—a conceptual understanding of physics. *American Journal of Physics*, *51*(4), pp. 305-311.

Krathwohl, D. R. (2002) A revision of Bloom's taxonomy: An overview. *Theory into practice*, 41(4), pp. 212-218.

Lage, M. J., Platt, G. J. and Treglia, M. (2000) Inverting the classroom: A gateway to creating an inclusive learning environment. *The Journal of Economic Education*, 31(1), pp. 30-43.

Martin, J. (2011) Advancing the flip: developments in reverse instruction. Blog entry, accessed 150524.

Mazur, E. (2009) Farewell, lecture? *Science*, 323(5910), pp. 50-51.

Prince, M. (2004) Does active learning work? A review of the research. *Journal of engineering education*, 93(3), pp. 223-231.

Roehl, A., Reddy, S. L. and Shannon, G. J. (2013) The flipped classroom: An opportunity to engage millennial students through active learning strategies. *Journal of Family & Consumer Sciences*, 105(2), pp. 44-49.

Tanner, K. D. (2010) Order matters: using the 5E model to align teaching with how people learn. *CBE-Life Sciences Education* 9.3: 159-164

Watkins, J. and Mazur, E. (2010) Just-in-time teaching and peer instruction. In Simkins, S. and Maier, M. (Eds.) *Just-in-time teaching: Across the disciplines, and across the academy*, Stylus Publishing.

Wiggins, G.P. and McTighe, J. (2005) *Understanding by design*. Alexandria, VA: Association for Supervision and Curriculum Development.