How a Flipped Learning Environment Affects Learning in a Course on Theoretical Computer Science

Dorina Gnaur[1] and Hans Hüttel[2]

[1] Department of Learning and Philosophy, Aalborg University, Denmark
[2] Department of Computer Science, Aalborg University, Denmark

Abstract. This paper reports initial experiences with flipping the classroom in an undergraduate computer science course as part of an overall attempt to enhance the pedagogical support for student learning. Our findings indicate that, just as the flipped classroom implies, a shift of focus in the learning context influences the way students engage with the course and their learning strategies.

1 Introduction

The notion of a flipped classroom has emerged in recent years [6] in the context of education in the United States. The idea is to use technology to move traditional 'in-class' activities out of the actual classroom, often in the form of audio or video podcasts. Practical sessions now become the central in-class activities. A common argument is that this will re-focus teaching on student-centered learning.

In this paper we assess experiences with a web-based notion of a flipped classroom in the setting of the course *Computability and Complexity*. The course has been taught by the second author since 2011. The course is followed by students in the third year of the undergraduate programmes in computer science and software technology. The decision to flip the classroom stems from two observations made by the second author in previous courses: firstly, attendance at lectures appeared to be notably higher than the attendance at the student-focused part of teaching in the course, e.g. practical sessions; and secondly, that many students appeared not to have read the texts associated with these teaching activities that depended on this. The hope was that a flipped classroom, through which the focus is purposely directed towards the active part of teaching, would induce students to embrace active learning, which is known to enhance deep learning.

Since a flipped classroom redefines teaching practice, it is important to understand its relation to the general teaching practice within the subject area. Every teaching activity within an academic subject can be seen in relation to its adherence to the underlying signature pedagogy, a notion due by Shulman who defines it as follows [11]:

> These are types of teaching that organize the fundamental ways in which future practitioners are educated for their new professions. In these signature pedagogies, the novices are instructed in critical aspects of the three fundamental aspects of professional work to think, to perform, and to act with integrity.

Computer science spans diverse scientific paradigms; in some areas, the signature pedagogy is related to that of pure mathematics with a focus on mastering formal definitions, theorems and proofs and on solving well-defined mathematical problems. Very

E. Popescu et al. (Eds.): ICWL 2014, LNCS 8613, pp. 219–228, 2014.

often the focus is on lectures that expound the material on the blackboard. This signature pedagogy is also characteristic of the course Computability and Complexity. The course, found in most computer science degree programmes today, covers topics in the mathematical theory of computation that are central to computer science and arose in the context of mathematical logic.

Signature pedagogies represent the distinct ways of thinking and practicing which are characteristic of a discipline [11]. The process of gradual initiation into the disciplinary field is marked by narrow passages into areas of increased insight, also called *threshold concepts*. One of the threshold concepts of the course is the integration of basic, declarative knowledge (in particular definitions and theorems), another that of being able to master the mathematical reasoning strategies associated with the course (that is, the proofs of theorems). The two concepts are closely linked, as mathematical proof strategies depend on the learner being able to integrate declarative knowledge that is, being able to 'speak the language' of the subject.

2 Theoretical Framing

Research in higher education pedagogy stresses learning rather than teaching and the importance of student centred activities to enhance learning [7,1]. The research indicates furthermore that students make decisions on learning approaches based on their perception of the learning objectives of a program component. In more general terms, they may decide on relatively superficial or on more in-depth approaches, and adopt corresponding strategies. Unless the subject matter is of inherent interest to them or elicits specific types of engagement or assessment requirements, students tend toward surface approaches to reduce workload and concentrate on what they perceive as more demanding components. It follows that the teaching and learning context has to be explicitly aligned with the intended learning outcomes of a course. As suggested by the theory of constructive alignment [1], the teaching system must align teaching methods and assessments to the learning activities stated in the objectives, the purpose of teaching being to support student learning towards higher complexity levels.

Students' perception of the course context manifests itself as a combination of intention and strategy: the level of knowledge they choose to pursue and the associated strategies they will apply to reach that level. Meanwhile, students encounter obstacles on the learning path; if they are unable to achieve set objectives, they may resort to 'mimicry' or other simulation strategies. This is another reason for students being stuck within surface approaches. Advancement within a field requires basic building blocks that integrate lower level concepts and continuously expand through new entries into the discipline as well as a gradual initiation into the ways of thinking and practicing that are specific to the discipline. [4].

If we want to understand how students get initiated into a discipline, a crucial notion is that of its *threshold concepts*. A threshold concept brings forth the idea of a portal that opens up

> ... new and previously inaccessible way[s] of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress [8]

In other words, threshold concepts are troublesome – but once a student has mastered them, the concepts are revelatory and irreversible, for they transform the disciplinary identity of the student and how he/she thinks about and practices the subject.

In this perspective, the task for teachers is to capitalize on key components of understanding as well as to locate 'stuck places' or inadequate approaches that may hinder students' progress, in order to align teaching methods in ways that facilitate learning. The learning context is meant to act as a 'holding environment' that will convince students to step outside their comfort zones and enter zones of uncertainty, while supporting their endeavours through the provision of adequate learning resources and technologies as well as access to enhanced student-teacher interaction [10]. Teaching is thus an expression of discipline-based pedagogy, i.e. 'the ways of representing and formulating the subject that make it comprehensible to others' including 'an understanding of what makes the learning of specific topics easy or difficult' [11, p. 9-10]. Technology serves intentional presentation purposes as well as enhanced access to disciplinary knowledge.

3 The Main Teaching Activities

In this section we describe the main teaching activities that took place in the course Computability and Complexity, henceforth abbreviated CC.

3.1 Pencasts and Text-Related Questions

The CC course used the Moodle e-learning platform [9] and was organized as 15 sessions. Each session (apart from one extended problem solving session) dealt with a specific topic, supported by textbook. A central goal of the teaching activities was to support the aspect of a thorough reading of the text related to the session. Previous anecdotal experience suggests that students are often not used to reading mathematically-oriented texts with an emphasis on precise definitions and on applying these. Therefore, the text-related questions focused on the declarative aspects of the learning goals with a set of text-related questions for each session. The answers to these constituted a personal portfolio, i.e. a collection of personal documents that were allowed at the final exam as the only aid. Students were supposed to submit their answers according to the deadlines indicated on the course Moodle platform. The answers must be written in LaTeXand were subjected to a peer review by a fellow student.

At the same time, the lectures dealing with declarative knowledge were replaced by a collection of pencasts. These were produced on an iPad using the Doceri app [2], a rubber-tipped stylus and an iPhone headset and later edited under Mac OS X using iMovie. Every session, apart from an extended problem-solving session half way through the course that recapitulated the material of the first 7 sessions, had an associated pencast consisting of 3 to 5 video segments each having a duration of 8 to 15 minutes. Each such segment addressed a part of the text associated with the session. The presentation style of the videos involved a combination of handwritten text and recorded sound; the intention was to stay close to the signature pedagogy of the subject and approach the exposition in the style of a chalk-and-blackboard only lecture, a mode of lecturing that the second author had used previously with good results. Fig. 1 shows a screen capture from a pencast segment.

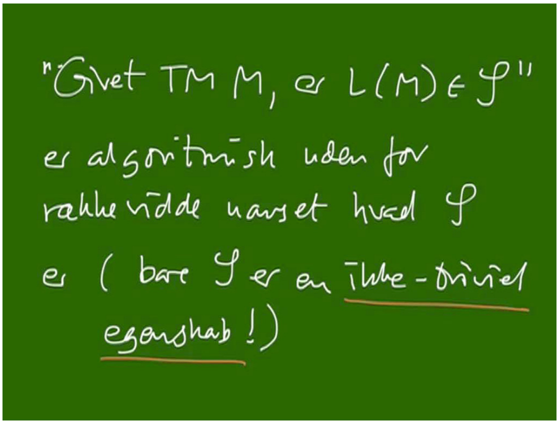

Fig. 1. Screen capture of pencast (in Danish)

As part of the pencast associated with each session, the exposition ended with a 'horror story' intended to highlight typical pitfalls and misconceptions within the topic of the session; this was an extension of the practice within the earlier lecture-based teaching by the second author. Students were expected to have watched the relevant pencasts and read the corresponding material in the textbook before the practical sessions. Each set of pencasts could be downloaded as a zip archive of Quicktime files released under the Creative Commons licence 3.0. All pencasts can be played on computers, tablets and smart phones. Initially, each pencast-based session was supported by a discussion forum on Moodle. However, the fora saw very little activity (only two questions were asked), so this idea was eventually scrapped.

3.2 Practical Sessions

Each pencast session had an associated practical session. Due to constraints on rooms, the students were distributed over three large seminar rooms for these practical sessions. Each practical session involved solving a problem set that would focus on central notions (definitions, theorems and their proofs and associated proof techniques). The problems in each set were deliberately chosen to be similar in form and content to ones that students would encounter at the final exam – as part of the alignment strategy.

4 Evaluating the Experience

The authors together prepared a questionnaire, which was followed up by 4 qualitative interviews with a total of four groups of students by the first author, who was unknown to the students and so less biased.

4.1 Analysis of the Questionnaire

At the end of the course, the students were given a questionnaire focusing on evaluating student learning. 40 out of 101 students answered these questions, which aimed at determining the perceived effects of pencasts on their learning experience. The following is a summary of the replies to two crucial questions. Fig. 2 summarizes the replies to the question of how students perceived that pencasts supported their learning. The vast majority felt that the pencasts indeed supported their learning. Note that the question about the usefulness in an exam setting may appear partly misleading as the answers were collected well in advance of the exam and can only represent a statement of intent on the part of the students.

	No. of students	Percent
They constituted an important means of having access to the contents of the course	22	55
They made it possible for me to plan my learning in the way that I preferred	24	60
They helped me catch up on topics if I had been away	20	50
They were a better way of approaching topics than a lecture would have been	15	37.5
They made it easier for me to prepare for the problem-solving sessions	22	55
They made it easier for me to prepare for the exam	17	42.5
None of the above	1	2.5
Other	4	10

Fig. 2. Students' answers to the question *To which extent did you experience that the pencasts of Computability and Complexity supported your learning?*

The students were also asked, which of the activities of the course that, in their opinion, were most helpful for learning. Fig. 3 summarizes the answers. The answers indicate that the intent of the teaching design, namely to emphasize the importance of problem solving, was fulfilled. Pencasts as such are not producing learning; yet they are valued in combination with an active learning element such as problem solving.

	No. of students	Percent
Text-related questions	0	0
Pencasts	1	3
Problem-solving sessions	5	13
Text-related questions together with pencasts	5	13
Text-related questions together with problem-solving sessions	8	20
Pencasts together with problem-solving sessions	13	33
The combination of all three activities	8	20

Fig. 3. Students' answers to the question *Which combination of activities was the most helpful for your learning?*

4.2 Analysis of the Interviews

The first author carried out group interviews with 2 groups of computer science students, and 2 groups of software students, that all followed the course. The students were offered anonymity in the sense of referring to the output as a common voice, with neither individual nor the particular group reference. The interviews were transcribed and analysed using an interpretivist methodology, where the emphasis lies on the ways a phenomenon appear to make sense to the involved parties in the specific situation (Erickson, 1998), and were codified as per the strong points within each group as well as the per the salient issues across the groups. The discussions were guided along various themes such as: study habits in traditional lecture-based courses and in a flipped setting; perceived benefits and disadvantages of pencasts; and student-teacher roles in the flipped setting. The quotes were selected across the groups, respective to how representative they were for the salient points.

Study Habits Regarding Lectures. Just as the second author had assumed, the interviews show that in all four groups students attend lectures without much preparation, just to orient themselves in the content knowledge so that they can make decisions for what is needed to solve practical exercises or to improve their current grasp of the subject. Lectures are mainly associated with declarative knowledge and a rather superficial view of learning oriented towards satisfying perceived exam requirements:

> What we need [from lectures] is an overview of the content to decide what we need for resolving the exercises. You rarely learn more than what is needed.

> Exams are based on resolving exercises and memorization (...) The exam tasks don't test whether you understand, but whether you can answer in a precise, specific way.

Meanwhile, the groups all agree that learning only occurs as the result of their active involvement with tasks and problems, or in other ways actively processing the specific field of knowledge.

> You don't learn by watching and listening, only by being active yourself, and here, the exercises and problems we have to solve ourselves, it's what you learn from.

> Pencasts make really good sense, when you just watch. Yet, we don't learn from watching. We only learn by being active ourselves, and therefore the practical sessions and whenever we sit together and solve problems, it's what we learn from!

Perceived Benefits of Pencast-Based Lectures. The pencasts are perceived as offering major advantages in enhancing study strategies, i.e. deriving concise theoretical explanations needed in order to solving problems in the practical sessions. They are valued for the possibility of revisiting difficult issues and rehearse for exams:

> I like the concept [of pencasts], because if I miss something or don't quite get it, than I can go back to it, as many times as I need, and whenever it suits me.. I don't function very well at 8 o'clock in the morning. A lecture is a one-take

> event. And especially when studying for the exam, it is really valuable to go back to the topics explained rather than pondering on what was meant on some topic at the beginning of the term. You just pick up the video clip and watch it afresh.

Furthermore, students appreciate the delivery efficiency in terms of the lesser time it takes to convey the actual content knowledge without the frequent deviations during normal lectures. Students indicate further presentational advantages such as delimiting theory from examples.

> I get the same out of it [pencasts] as from the lectures, and we skip a lot of superfluities. With pencasts, you get the same content, effectively explained in only half the time.

> I wish that the pencasts were divided in theory-only with reference to 1-10 examples separately (. . .) we don't dare skip any of them out of fear for missing some important theoretical point.

Perceived Drawbacks of Pencast-Based Lectures. Students are generally enthusiastic about pencasts and argue for their usefulness as a learning resource. When asked about the possible drawbacks, they point to the lack of possibility of spontaneously asking questions and suggest compensatory strategies in the form of quality time', i.e. enhanced interaction with the teacher:

> It would be nice to meet in class once in a while, say after the first part of the course, for a summing up and discussion of the main points and the possibility of asking questions . . .

> . . . that little thing that you could always interrupt and ask a question to understand how he got from this step to that step . . . it's difficult with pencasts.

> There should preferably more time with the teacher to focus on individual questions, now that he doesn't use his time lecturing anymore, going in depth with issues that give us problems.

Paradoxically, this also makes students value and attend to the interactive part of the teaching, as was the intention:

> We would prefer a 50-50 % distribution between digital presentation material and face-to-face interaction at university – mainly for the practical or active sessions including some lectures, especially in subjects that require discussion.

Students distinguish between courses that may benefit from digital mediation, i.e. those containing theoretical, factual knowledge; and ones that may not fit this format, including ones where interactivity and discussions are seen as instrumental to learning. Nevertheless, the interactive aspect of learning is valued also in the context of theoretical courses.

> Pencasts are better for the more theoretical courses, like CC, it's here that you need to watch again and again. While courses like 'Design of user interfaces', well here it wouldn't be just as relevant because it doesn't matter if you miss something (. . .) because it's a much more fluid course: in design, there is not much right or wrong, it's more like: this is right in this context and the opposite may also be right.. It's the discussion, some course types or some teachers insist more on the discussion, and if you engage actively, then you really learn a lot! It's not possible with podcasts, therefore it's mainly the theory and some standard demonstration that you can store like that. But I really don't think that we should just give up the discussions in the theoretical courses either, therefore I'm happy that we have kept the practical sessions intact, so we can discuss the things with him.

Furthermore, students favour technologies that support elements of signature pedagogies, such as processual explanations using the blackboard:

> Power Point slides with voiceover would perhaps be more suitable for software courses, with the many models, but here, where we have so much theory and definitions, it's better to use technologies that remind of the blackboard.

4.3 Conflicting Learning Strategies: Flexibility and Control

Students had to comply with a scheduled plan for submitting answers to text-related questions and for peer reviews of answers; in the interviews students expressed dissatisfaction with these deadlines and what they saw as a contrast to the flexibility paradigm introduced by pencasts.

> It is problematic because we are forced to keep some deadlines that don't make sense (. . .) because you don't have the time to work seriously with the theory. Yet, if we don't deliver in time, we can't take it in at the exam. I don't understand why we can't just have one final deadline, sometime before exam, so we can still make it, only not so tight. The idea of peer feedback is fine as such, we do it all the time, in group work. The problem is when it is forced, because then we have to do it in a more superficial way than if it fit our study plans.

Similarly, in order to support students in viewing the pencasts on an ongoing basis, and preferably in the company of peers, these were scheduled for viewing in class, as in-between sessions, i.e. between two on-campus activities, with the possibility of asking questions in a virtual forum, with synchronous teacher assistance. However, few students actually watched the pencasts at the times scheduled and perhaps therefor, the virtual fora saw very little activity.

Generally, all groups agree that pencasts are a very good alternative and/or a supplement to the ordinary classes, particularly in more theoretical courses. Yet, they would far from having all courses digital as they would miss the human contact and possibility of interaction. Similarly, it might alter the very act of studying, making it difficult to navigate the learning process:

Pencasts, and so on, means flexibility, so they are welcome. Yet we wouldn't like all courses to be that way, it would feel whirred... then you just sat there with a pile of pencasts that you had to go through every week, having to find the time to just watch through the whole lot.

5 Conclusions and Further Work

We have studied the pedagogical aspects of a web-based flipped classroom setting in a 5th semester computer science course. Essential to the setting was that it should emphasize teaching activities that encourage deep learning and emphasize the threshold concepts of the subject area.

The CC course has two central threshold concepts that interact, one being the integration of declarative knowledge of definitions and theorems, the other being the procedural knowledge associated with mathematical reasoning strategies for understanding and proving theorems. Pencasts and text-related questions were intended to emphasize both of these, while practical sessions mostly focused on the latter.

The survey conducted indicates that the experience was in many ways positive. Interviews showed that students approved of the emphasis being explicitly moved towards active learning in the form of using pencasts to prepare for the practical sessions, which were appreciated as an opportunity for learning through interaction with teacher and peers. Students also seemed to agree that the pencasts would be particularly useful in preparing for exams as they support the retrieval of learning cues from the original context. In further work, we plan to investige if and how the pencasts and similar material can be used by students when preparing for exams and other forms of summative assessment.

Students' learning intention for the CC course was the acquisition of declarative knowledge through a postponement strategy of studying for the test. The pencast delivery option matched their learning intention and was highly appreciated for the inherent flexibility, time efficiency and rehearsability option in view of the exam. However, this rather superficial approach to learning was challenged by the teaching design that aligned the intended learning outcomes [1] with the ongoing processing of the subject content through text-related questions and peer feedback to support the continual integration of declarative knowledge, as well as through the development of performative competence through problem solving sessions.

This is in agreement with students' very own perceptions of learning as the result of active engagement and problem solving, yet not to their first choice of strategy. This shows how a minor shift in the learning context induces students to reassess the role of active learning, and to value the teacher-learner interaction in this context.

It is important to note that just as the flipped environment was inspired by the unflipped one, the students also saw the new learning experience through the lens of their normal lecture experience. Thus, their concerns about the lack of interaction with the teacher may be a consequence of this. The web-based fora for discussion certainly turned out *not* to be a relevant means of student-teacher interaction. As intimated by their testimonies, the student-teacher interaction might see new qualitative heights when re-directed towards the active dimension of teaching and learning. Another direction for further work is to investigate how teacher-student interaction can be strengthened in this particular flipped setting.

It is unclear how convinced the students may have been while working with the text-related questions, as it appears that they may have been subject to the double-bind of resistance to fixed deadlines, and the interest in producing exam support material. Arguably, the teaching strategies to support learning goals should not overrule student learning strategies, but seek to meet them by agreeing on the actual rather than perceived intended learning outcomes for the course and negotiate appropriate teaching and learning strategies together with the students.

This would be an adequate opportunity to render explicit the aims of the course in terms of the threshold concepts, which might otherwise be elusive to them. It might shed light on the necessary constituents of a holding learning environment, meant to support students in withstanding states of uncertainty and provide a good training ground. In other words, making the implicit design explicit might benefit student engagement. The study of how to best achieve this is also a topic for further work.

In conclusion, flipping the classroom is not a universal formula for effective teaching but an opportunity for rethinking the teaching design and aligning it with intended learning outcomes. It helps in reorganising the learning context with due regard to what is essential to learning, i.e. students' active engagement and a qualitatively enhanced interaction with the teacher. It points at the need to employ learning technologies to support and if necessary alter signature pedagogies in according with the overall learning and teaching strategy.

References

1. Biggs, J.: Teaching for quality learning at university. Society for Research into Higher Education and Open University Press, Buckingham
2. Doceri - the Interactive Whiteboard App, `https://doceri.com`
3. Erickson, F.: Qualitative research methods for science education. In: Fraser, B.J., Tobin, K.G. (eds.) International Handbook of Science Education, pp. 1155–1173. Kluwer Academic Publishing, Dordrecht (1998)
4. Entwistle, N.: Teaching for understanding at university. Deep approaches and distinctive ways of thinking. Palgrave Macmillan, Basingtoke (2009)
5. Entwistle, N.: Understanding classroom learning. Hodder and Stoughton, London (1987)
6. Hoffman, E.S.: Beyond the Flipped Classroom: Redesigning A Research Methods. Course For e3 Instruction, Contemporary Issues In Education Research 7(1) (2014)
7. Marton, F., Hounsell, D., Entwistle, N. (eds.): The experience of learning. Scottish Academic Press, Edinburgh (1997)
8. Meyer, J.H.F., Land, R.: Threshold concepts and troublesome knowledge: linkages to ways of thinking and practising. In: Rust, C. (ed.) Improving Student Learning - Theory and Practice Ten Years On, pp. 412–424. Oxford Centre for Staff and Learning Development (OCSLD), Oxford (2003)
9. Moodle, `http://moodle.org`
10. Savin-Baden, M.: Learning Spaces: Creating Opportunities for Knowledge Creation in Academic Life, pp. 25–26. McGraw Hill, Maidenhead (2008)
11. Shulman, L.: Signature pedagogies in the professions. Daedalus 134(3), 52–59 (2005)
12. Shulman, L.: Those who understand: knowledge growth in teaching. Educational Researcher 15(2), 4–14 (1986)