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Flipped Classroom Teaching For A Cyber-Physical System Course – An Adequate Presence-Based Learning Approach In The Internet Age

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***Abstract*—In the age of the Internet, teaching styles need to take new ways of learning into account. This paper recommends the use of the flipped classroom approach. In this approach, the roles of work at home and in class are essentially swapped. We present a case study covering a course on cyber-physical system fundamentals. Results are strongly encouraging us to continue along these lines. We are also commenting on general advantages and limitations of this style of teaching.**

I. Introduction

The availability of information on the Internet has changed students' approach to learning. More emphasis is placed on the development of skills and less emphasis is placed on knowledge. Students tend to look for needed knowledge on the Internet. This applies also to the way students try to pass exams. They are looking for slides and available courses on the Internet. In this way, attendance at lecture-based classrooms is frequently considered to be less important.

A contemporary style of education should take this into account. Support for students enrolled at a particular university should focus on the development of skills and knowledge which cannot be obtained via other mechanisms.

Much of the focus on the exploitation of the Internet for education is currently on massively open online courses (MOOCs). However, MOOCs aim at reaching students who are unable to attend courses at the educational institute offering the MOOC course. Management at such institutes has some interest in making the institute well-known by its MOOCs. In this way, external students (off-campus students) get access to courses they could otherwise not attend. However, internal students (students actually enrolled as on-campus students) are typically the key target group of educators at such institutes. Such students benefit only to a small extent if lectures continue to be held in traditional style. Benefits are limited to the ability to listen to educators' explanations asynchronously.

Contemporary technology is used in a different way in the so-called flipped (or inverted) classroom approach. In the flipped classroom approach, the roles of attendance in class and work at home are essentially swapped. Basic knowledge in the area is now obtained at home and the use of this knowledge to develop skills is done in class. In this paper, we will be demonstrating how this approach has helped us to overcome problems in teaching our course on embedded system fundamentals of cyber-physical systems.

This paper is structured as follows: Section II presents our approach for flipped classroom teaching of this course. The section contains subsections covering the characteristics of the course, the recording of the videos, face-to-face meetings, and lab/exercise sessions. Section III discusses related work. The rather unusual placement of this section is motivated by the logical structure of our arguments and explanations. An evaluation of the approach is presented in Section IV. This section comprises observations made for our course, links them to related work and explains how advantages and limitations of the flipped classroom concept may differ between subjects. Section V contains the conclusion.

II. Flipped classroom approach for the course "cyber-physical system fundamentals"

A. Course characteristics

The course "cyber-physical system fundamentals" (CPSF) covers embedded system fundamentals to be used in the broader cyber-physical system context. It is a mature course based on a companion textbook. The textbook was first published in 2003 [1]. The second edition became available in 2010 [2]. The textbook covers the following topics:

1) Introduction (applications, challenges, design flows)
2) Specification and modeling (models of computation: state machines, data flow, Petri nets, discrete event models, von Neumann model, etc.)
3) Embedded system hardware (hardware in the loop, A/D- and D/A-converters, embedded processors, memories, FPGAs)
4) System software (real-time OS, priority inversion)
5) Evaluation and validation (Pareto optimality, estimation of various objectives)
6) Application mapping (scheduling, hardware/software partitioning, multicore mapping)
7) Optimization (high-level source to source optimizations, compilers for embedded systems, power and thermal management)

8) Test (test patterns, test applications, result comparison, design for testability)
9) Appendix: integer programming, Kirchhoff's laws, operational amplifiers

The textbook has been translated into Chinese, German and Macedonian. Slides and small simulators have been made publicly available [3]. Due to the level of maturity reached, the rate of changes to slides and other material is low. CPSF is taught in a master program called "automation and robotics". Students are mostly foreign students holding heterogeneous Bachelor's degrees in electrical engineering, mechanical engineering or computer science.

For many years, classes were taught mostly from the tablet laptop. The laptop was used for Powerpoint slides (with animations and annotations), simulations and for showing short movies and visualizations. Fig. 1 shows a screenshot of the simulator for Kahn process networks.

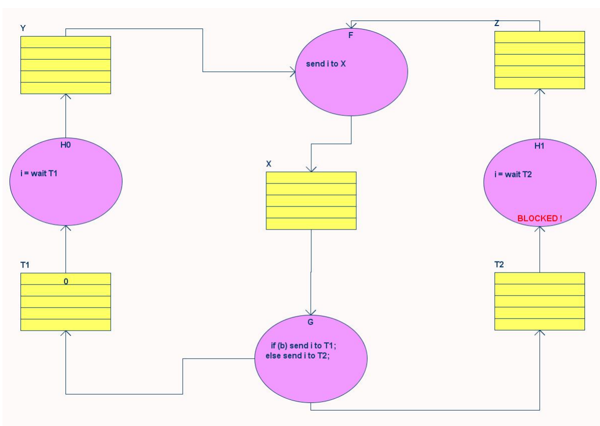

Fig. 1. screenshot for KPN simulation

Highlighting particular parts of the slides was done by using the laptop cursor. A special red cursor pointing from the left to the right was created in order to guarantee good visibility on white slides. In this way, it was easy to always look in the direction of the laptop and the audience. The white board was used only occasionally. Turning the head towards the white board or screen was not essential. This helped to keep the audio quality at a high level. The amount of interaction with the students was small, despite all attempts to increase it.

B. Recordings

In 2010, we decided to increase the maturity of the course to the next level: we decided to record the lectures. We assumed that both our on-campus as well as our off-campus students would benefit. Due to our style of teaching, we could easily give up on the use of the white board and reduce interactions. A better video and audio quality more than compensated for the loss of the white board. In some cases, we replaced the white board by sketches on the tablet PC. We wanted to make recorded movies freely available and, therefore, we replaced copyrighted movies by a link to the movie. For this very first recording, we had to cope with a variety of technical problems. The audio quality was not always perfect. The recording software (Camtasia) crashed whenever we showed a video in the classroom, obviously due to an overload situation at the laptop. Servers at the central IT facility could not be used to host our videos. Nevertheless, we managed to publish videos on our own video server.

In 2012, we decided to re-record the lectures, taking advantage of the lessons learned. Recording took place in an external frame grabbing box which was capturing the video stream from the presentation notebook. For audio, we relied on a hand-held, wired microphone. The resulting videos were cut into chunks of 20-30 minutes and stored on YouTube [4]. Fig. 2 shows a screenshot of one of the videos. The black area was intended to be used for pointing towards the companion textbook, but time did not permit to implement it.

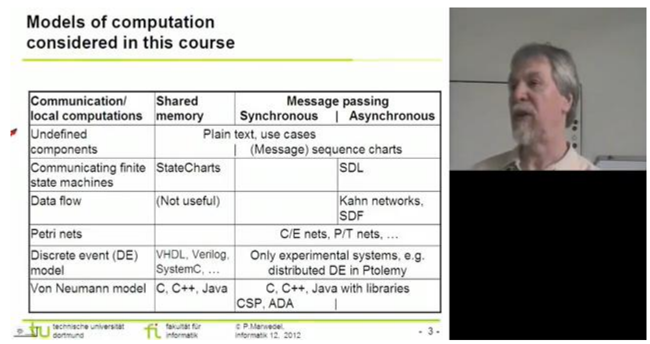

Fig. 2. screenshot for youtube video

Due to the availability of the videos, student attendance dropped dramatically. They all seemed to assume that it would be sufficient to watch the videos just before the finals. However, watching about 40 hours of technical videos just before the finals is not feasible. Attendance at the finals also dropped to an unacceptable level of about three students.

C. Transition towards flipped classrooms

By 2013 the latest, we realized that we have to break away from traditional classroom teaching. In a discussion with colleagues in the US, the term "flipped classroom" was mentioned. We decided to give it a try. We ran the course as follows:

The first two lectures were held in the standard way in order to make the students familiar with the topic. Also, due to a conference, the first two lectures had to be presented by a post-doc. All following meetings with the students used the following scheme:

1) Five minutes of a quick walk through the (about 40) slides which were relevant for that meeting. The main purpose was to remind the students and emphasize certain aspects which had either had undergone changes since the recording or that were relevant details for the assignments which followed.
2) Next, students were requested to work on assignments on worksheets which were unknown to them before the meeting. Students worked in groups of 2-3 people on

these assignments. An open book policy was applied: students could use the textbook or the slides. We, as the organizers of the course, could watch and help the students while they were solving the assignments. In case of general problems, issues could be discussed at the white board or on the tablet laptop. Typically, 2-3 worksheets were used per meeting. After the meeting, worksheets were made available to the students in a closed web space. In some of the more difficult cases, correct answers were made available together with the worksheets.
3) The last five minutes were used for a preview on the next meeting.

The following list contains simplified examples of questions which we raised on the worksheets:

- Definitions covered in the introduction
- Classification of models of computation
- Hierarchical state graphs and their reaction to inputs
- Manual simulation of synchronous data flow (SDF) graphs
- Manual simulation of Petri nets
- Manual simulation of a flip-flop using discrete event simulation
- Explanation of values in IEEE standard 1164 for multiple-valued logic
- Model of a bus using IEEE 1164
- Model of an A/D converter
- Comparison of the results of wrap-around and saturating arithmetic
- Definition of Pareto-optimality
- Worst case execution time estimation
- Solutions for scheduling problems.

Initially, we insisted on students being present during at least 50% of the meetings, since physical presence is so important for this type of lecturing. After a while, we could drop this requirement, since the students were showing up anyway. Obviously, they had realized that the meetings were preparing them for the finals and that every missed meeting could immediately lead to a poorer grade in the finals. In general, the students seemed to be well-prepared. Only two students (out of some thirty students) with a strong background seemed to be solving the assignments on the spot. Two students had continuing problems.

D. Labs and exercise sessions

In our environment, it is common to have lab or exercise sessions, which are in many cases run by teaching assistants (PhD students). In case a course includes some practical training, these sessions typically serve two purposes: they are used to provide some hands-on experience with computers and tools and they are used to present (pencil-and-paper-based) solutions to problems which are linked to the lectures. In the first case, the target is to make sure that the students obtain practical skills and learn how to use exemplary tools. In the second case, the material is covered from a more theoretical approach. This is the material which is typically used in the finals since practical skills are more difficult to test in the finals. This leads to a conflict between training practical skills and preparing students for the finals.

In the flipped classroom setting labs/exercise sessions were continued. However, they were re-designed to focus exclusively on practical skills, the use of computers and available tools. In a way, this resolves the conflict described above.

For our course, we used the following tools:

- A tool for the description of hierarchical state diagrams (dave, a locally developed tool)
- IAR VisualState®StateCharts design and compiler tool
- Lego® Mindstorms® autonomous robot programming using LabView® (considered very relevant for a program on "automation and robotics")
- The open source `ghdl` VHDL simulator

Having more time available for such hands-on sessions was really beneficial. In fact, this benefit of flipped classroom teaching is a benefit which is specific for **all** courses for which hands-on training is essential. This includes many courses in computer engineering. This benefit is not available in a standard course on, say, theoretical computer science.

Many students like practical training, since they consider practical skills to be essential for their job in industry. There is, however, a potential pitfall for lab sessions which focus on practical training: skills obtained in this way are typically not checked in the finals. We are aware of two possible solutions: either we check skills obtained in this practical training also during the finals (difficult for large classes) or we allow students to participate in the finals only when they have succeeded in the practical training (our approach).

E. Finals

Overall, there was a large set of assignments included in the worksheets. This set covered the topics of the course very well. We had the impression that students who studied all the assignments in detail had essentially studied all relevant topics. Therefore, it was possible to use a subset of them to design the finals. Hence, from a lecturer point of view, worksheets also helped to find problems for the finals.

In order to prepare themselves for the finals, students also used the worksheets. In this respect, the worksheets also helped the students to better understand what the finals may be like. Hence, we could drop the dry-run for the finals which we had offered earlier.

III. Related work

The flipped classroom approach is not completely new. There are many similarities to the seminar-style of teaching in social sciences. In such approaches, reading a large amount of material at home and discussion in the classroom are standard. However, in science and engineering, there was the idea of the need to teach fundamentals in the lectures before the focus can be shifted towards discussions. This has changed with the availability of videos, and especially with the availability of videos on the Internet. Videos can replace the explanations of educators. These explanations seem to be needed by many students, i.e. those who are not able to pass exams after reading only books. In this sense, videos provide an added value if compared to books.

Flipped and inverted classroom based teaching have been proposed by several educators. There is a well-written Wikipedia article on the subject [5] which provides valuable links. Several recent publications (e.g. [6], [7]) describe the positive effects of flipped classroom teaching. D. Black-Schaffer describes the advantages of flipped classroom reaching in a video [8]. Also, he presented the subject at the HiPEAC conference in 2013 [9]. A German video [10] describes advantages of the approach, using math education as an example.

Keengwe, Onchwari and Oigara [11] mention the fact that the flipped classroom approach has been used across many areas, including math, English, science and other disciplines. Bergmann and Aaron also explain how the flipped classroom approach is helping to actively engage the students [12]. In general, the mentioned references stress the fact that the flipped classroom approach is a more effective approach to learning. Instead of just passively listening to lectures, students are now actively involved. Theories of learning clearly confirm that the impact of active learning is much larger than that of passive learning. Also, educators gain time to care about students individually instead of using most of the time to present the material. In this way, heterogeneity among students is easier to handle. The mentioned references contain details on how to design the video material and how to design the courses as a whole. In some cases [10], [8], rather short video clips and interactive checks are recommended.

In a more general context, we have to mention massively open online courses (MOOCs) as well. There are a couple of providers of such courses, like edX, Coursera, iversity, and Udacity. For MOOCs, the focus is on education of students not attending a university physically. However, due to the low percentage of students participating in the finals, the idea to combine MOOCs with presence-based learning came up. For example, MOOC courses could be taught with the help of a local teaching assistant. This could decrease the cost of education but it would eliminate the feedback between students and professors.

IV. Evaluation

A. *Observations in our course*

From our point of view the experiment was a full success. Some thirty students were attending the face-to-face meetings. Attendance at the meetings remained essentially constant over the duration of the course. There was a very interactive atmosphere during the meetings. All students were eager to solve the problems on the worksheets.

Flipped classroom teaching had a measurable impact on the use of our textbook. Our university library owns some twenty copies of the textbook underlying the course. Before switching to flipped classroom teaching, only a disappointingly small number was in use by the students. After the switch, essentially all the books were lent to the students.

The student evaluation was very positive. Students praised the new style of teaching. They mentioned that they could no longer fall asleep in class. One or two complained about having to watch videos for four hours per week at home. However, this was exactly the workload expected from the students. It seems like some students are now working at home as much as expected.

Some thirty students attended the finals. So, we avoided the drop in attendance and went back to a good number of students completing the course. Grades of the students were significantly better than in previous years. Nevertheless, a small number of students failed even with this approach.

We intentionally did not chop the videos into pieces as short as 5-10 minutes, as it is sometimes recommended. We believe that students should be trained to maintain attention for 30 minutes. Also, we did not add self-study questions. This would have increased the production effort tremendously. We have not observed a negative impact of the fact that we did not integrate self-checks into the videos. Also, we have not observed negative impacts resulting from the length of the videos.

B. *The pros of flipped classroom teaching*

In the age of the Internet, education in class should focus on teaching methods which take advantage of the students being present. Standard lectures fail completely in this respect. Lectures with a low level of interactivity can be replaced by videos. Videos provide additional advantages. For example, videos are typically of higher quality compared to the usual lecturing. Students can watch them any time and they can have a break if needed. In the flipped classroom approach, we take advantage of the students being physically present in class. We are reasonably sure that in fact every student has worked on the worksheet. Students are trained to apply the concepts discussed in the videos. The re-discovery of the usefulness of reading books is a welcome by-product.

In the flipped classroom approach, the educator obtains an early feedback regarding the level of the skills available in students. This allows to quickly add additional explanations etc.

The approach also trains students for teamwork. Being able to work in a team is essential for today's workplaces.

C. *Applicability*

We would not apply the flipped classroom approach to freshmen (this is also consistently mentioned in the references above). We believe that freshmen need to get used to physically attend a lecture, to get to know the educators and to avoid getting stuck in their own thinking without meeting their classmates. Also, discussion in groups works reasonably well for up to some thirty students. For larger courses, more parallel meetings can be organized. However, this approach would reach its limits with about four parallel sessions, since consistency among those sessions becomes non-trivial. Hence, we consider flipped classroom teaching to be limited to about 120 students, less than the number which we see in freshmen courses.

The flipped classroom approach needs videos. Videos should be recorded in a real class, since videos recorded in a studio tend to become boring (this is also mentioned by Loviscach [10]). Hence, one iteration of the course is required before we can switch to flipped classroom-based teaching. This does also mean that the course needs to be reasonably stable and mature. Hence, courses on very recent research results are less appropriate for flipped classroom teaching.

In our approach, lab/exercise sessions focus exclusively on the use of computers and tools. This is great for cyber-physical or embedded system design and, in general, for topics for which teaching practical skills makes sense. Whenever the use of computers and tools makes less sense (like in theoretical computer science), this additional presence phase is not needed.

Replacing a highly interactive lecture by videos is not recommended. According to our experience, only very few lectures are highly interactive.

Some of the flipped classroom style of teaching can be applied even in cases in which videos are not available, for whatever reason. In these cases, worksheets can still be used during lab sessions. Training the students for team work and positive effects on the finals do still apply.

In general, we can ask ourselves: how much of the approach used for cyber-physical education can be applied to other topics as well? We believe that a complete swap of the purposes of presence phases and learning at home works for mature courses with at most moderate changes in the material covered. The size of the course should allow supervision of students during presence phases. We distinguish between different types of benefits.

- The largest benefit arises when lab/exercise sessions can be re-designed to focus on practical skills and when they can be relieved from pencil and paper and from discussions at the white board. From this discussion, it is obvious that most computer engineering and microelectronic courses will benefit from this approach. The large benefit also applies to courses on algorithms, programming, operating systems, data bases, etc. if they include practical training.
- A smaller benefit remains in cases where lab/exercise cannot be redesigned, e.g. because they are not offered anyways.
- A smaller benefit exists as well for the combination of traditional lectures and worksheet based labs. This combination may be useful if the course is held for the very first time.

The references listed above also mention topics such as pure math and English to be taught with the flipped classroom approach.

V. Conclusion

In the age of the Internet, the role of presence-based learning has to be re-thought. Standard lectures do not take advantage of having the students personally present in the class. The flipped classroom approach addresses this issue. In the flipped classroom approach, we stimulate interactions between students. Exceptionally large benefits can be achieved in cases where the role of exercise sessions can be re-designed, like in our course. We believe that universities must take up this approach to teaching. Otherwise, there would be the serious risk of becoming redundant for teaching very much in the same way in which other professions have lost their role in the presence of the Internet.

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