Flipping the Classroom and Turning the Grades: A Solution to Teach Phase Diagrams to Engineering Students

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Abstract: In higher education at applied universities phase diagrams are introduced already in introductory material science courses for mechanical, automotive and economical engineers. Phase diagrams may simply be described as alloying maps in material science to help characterize microstructures and properties of engineering materials. However, the required thermodynamic background knowledge is considered high level and understanding of the cooling procedure of metal melts as well as microstructure of metal alloys is challenging. Common teaching material presents phase diagram as a working tool, but does not explain how to interpret the microstructure of materials and leaves frustrated first year engineering students behind. Knowledge on "how to read" phase diagrams is expected from students in advanced courses, but requirements are seldom met. Teaching phase diagrams in an "inverted classroom" scenario is a method to let undergraduate students in their first year study the science on their own and then take time to discuss their questions and do extended hands on lectures or exercises in class. Implementing the inverted classroom approach in an introductory material science course at HTW Berlin has been proven to be successful in terms of learning outcome, problem solving skills related to phase diagrams and in improving grades. Although the time of preparation for eight contact hours is raised by a factor of approximately four, the positive and sustainable learning outcomes make it fun to teach and worth the effort. This study aims at a successful method to gain sustainable knowledge on how to read and interpret phase diagrams and increase the students motivation.

Keywords: higher education, first year students, video lecture, inverted classroom, phase diagram.

Introduction

Teaching concept: "inverted classroom" for material science

The material science course for first year mechanical engineering students at HTW Berlin is taught via the "design-led" teaching approach (Ashby et al., 2013, exceLlus, 2016, Pfennig and Hadwiger, 2016, and Pfennig, 2016). In contrast to the conventional "science-led" teaching approach which begins with the physics and chemistry of materials, progressing from the atomistic through the microstructure to the macroscopic properties: the design led approach starts with the needs of the design and then explains why and how properties can be influenced and changed (Figure 1).

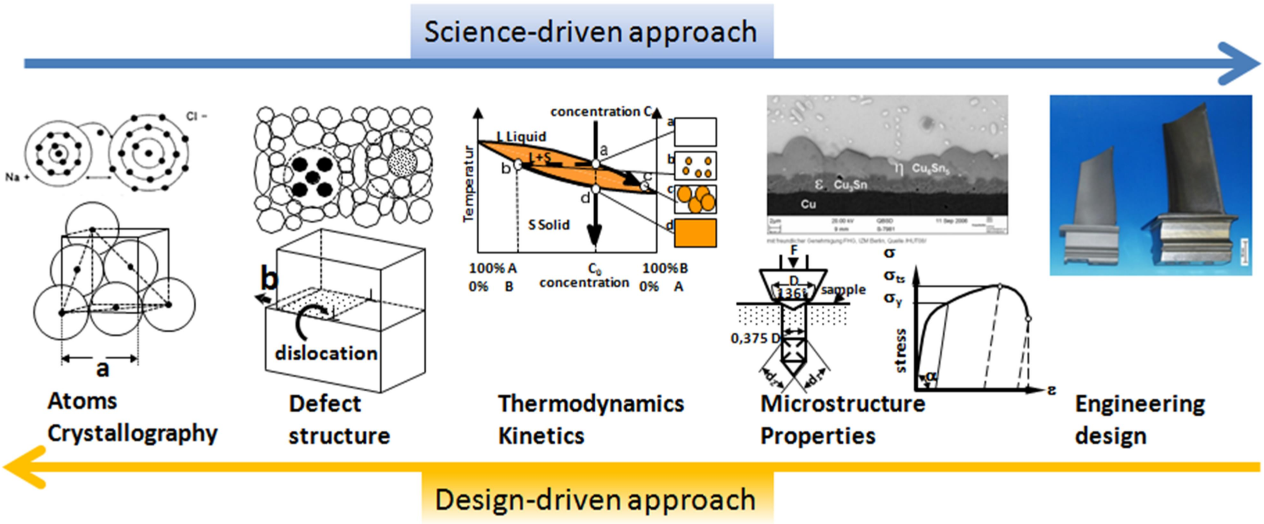

Figure 1. "Science-led-approach" and "design-led-approach", adopted from Ashby et al. (2013).

Teaching via "inverted classroom" scenarios (Pfennig, 2016) is a method to let the students study the science on their own and then take time to discuss their questions and do extended hands on lectures or exercises in class. Berret (2012), Brame (2015), Fischer and Spannagel (2012), and Braun et al. (2012) proved this teaching method successful to gain student`s attention, thus acquire good exam results. Lecture films (OLP, 2016, and Pfennig, 2016) were chosen as one of the main resources students acquired their scientific background from besides a variety of teaching materials such as micro module lectures, worksheets and worked solution, mind maps, glossaries, memory sheets, online tests and web-based-trainings WBT (Pfennig und Böge, 2015, Pfennig and Hadwiger, 2016). An important issue of the concept is, that the students were able to study individually, self-directed, location-independent, asynchronously and according to their individual tempo. In class there is time to discuss problems, work on exercises and engineering related problems in small groups, share difficulties and thoughts with neighbors and classmates.

In first year material science in mechanical engineering, the following themes are taught via "inverted classroom" scenarios indicating improvement of learning skills and grades compared to front classroom teaching methods (Pfennig, 2016, Pfennig and Hadwiger, 2016, Pfennig and Böge, 2015):

- Defects in crystals
- Heat treatment
- Introducing microstructure and materials families
- Phase diagrams and the Iron-Carbon phase diagram
- Hardening mechanism
- Nomenclature of materials
- Steel qualities
- Fiber reinforced polymers
- Introduction to polymers

Phase diagrams describe phase changes as a function of time and concentration of the alloying element during cooling of a liquid alloy. These can literally be understood as maps to understand the resulting microstructure of an engineering material. The microstructure directly relates to material properties such as ductility and strength. However, because the underlying thermodynamics are advanced for first year students studying phase diagrams is known as the most difficult theme in materials science. Mechanical engineers generally do not have to understand the calculation of a phase diagram, but it is important for them to interpret and know why and how an alloy shows the particular microstructure. Phase diagrams and how to interpret, read and transfer their knowledge onto real microstructures of materials seem to be an awful hassle for first year students. Due to the requirements of the curriculum, this theme has to be taught in first year engineering studies at HTW

Berlin. Common teaching material presents results, but not how to get there and leaves frustrated first year engineering students behind. Knowledge on "how to read" phase diagrams is expected from teachers in advanced courses, but requirements are seldom met by the students. Therefore, it is much more successful to engage the students into practical work and team assignments where they have to use their knowledge rather than listening, copying notes and memorizing during class. During a period of two years teaching material was rearranged in such a matter that students were able to understand phase diagrams during self-study phases.

Between 2015 and 2016 students got very good results when preparing lectures, watch introductory films (Online Lehre Plus, 2016) and do homework exercises prior to the lecture in presence. In class we had time to discuss problems, work on exercises and engineering related problems, share difficulties and thoughts with classmates and especially experience that the background information (self-taught at home) delivered a great deal of understanding of the correlation between materials properties and microstructure. Among others study materials are:

- Micro module lectures intermixed with problems and worked solutions
- Worksheets and worked solutions
- Lecture videos (actual semester) and teaching videos: Pfennig and Hadwiger, 2016, Pfennig, 2016-1)
- (interactive) Mind maps
- Memory sheets to memorize most important aspects
- Online tests (for self-testing and assessing through lecturer)

Still, a mixture of teaching methods prevents boredom, predictability and preferences of certain learning types. Surprising the students by implementing different learning materials and teaching methods increased attention, attentiveness and raised grades and learning outcome.

The aim of this study is to demonstrate how the inverted classroom method may already be introduced to first year mechanical engineering students to teach unbeloved phase diagrams and gain deep understanding how to apply these properly to interpret microstructure and properties of engineering materials. Quantitative data were collected to explore the following research questions:

1. How do students respond to the inverted classroom teaching scenario?
2. How do grades change?
3. What is the role of lecture videos during self-study periods?

Methodology

Introducing Phase Diagrams

Home assignment and contact time

General phase diagrams and the iron carbon phase diagram were briefly introduced in class. After an extended self-study period hands-on problems were solved in class along with detailed discussions among the students. Both, homework assignments and in-front lecture contributed to a profound understanding and good results on phase diagrams.

General phase diagrams

The 4-hour lecture on phase diagrams was filmed in SS2015 and cut into 9 videos with distinct headlines so that each student could easily navigate to understand how to read phase diagrams (Figure 2). Self-studying of this introduction to phase diagrams was assigned via Moodle one week prior to the face-to-face lecture.

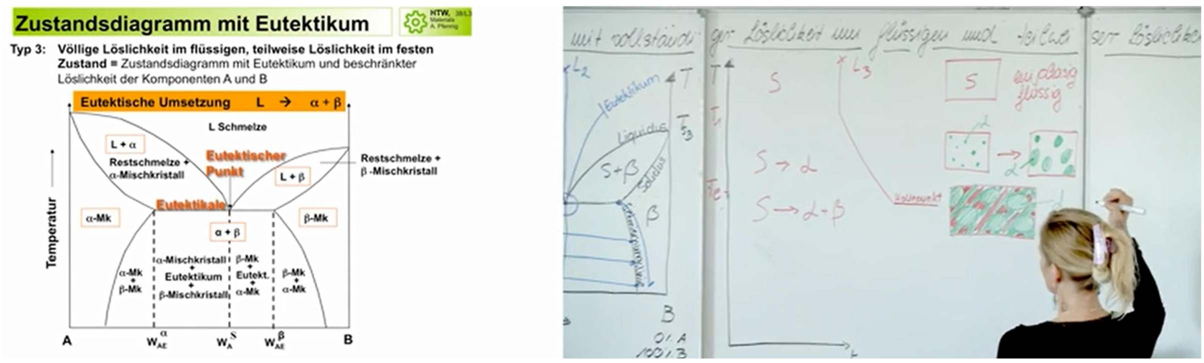

Figure 2. Lecture video: phase diagrams (11 lecture films) (2:35 hours), (https://www.youtube.com/playlist?list=PLUOlZMSZYz5zha5EbwAKrQ8w8W65ST3fN)

After a one week self-studying period it was necessary to get an overview of the knowledge the students gained in order to successfully proceed with the solving of individual problems. Therefore, the open-source software *invote* (invote, 2016) was used in class for peer questioning (Simon et al., 2010, Pfennig, 2015, Pfennig, 2016). Students got a good idea on their own background knowledge and the lecturer was able to decide if the level of necessary knowledge of the entire class was sufficient enough to pass the hands-on problems and the evening exam. Each question gave the opportunity to discuss the right answers and especially the distractors. If most of the students gave false answers it was necessary to go into this particular problem in more depth and explain details. Questions that aroused during self-studying were answered in the plenum and important issues were explained again individually by the lecturer.

After this introduction students were divided into groups of four. Twelve assignments of different levels were categorized into: 1.) pass the class, 2.) pass with C or B, 3.) pass with A or even better. These were all stacked in different piles of the same assignment and offered to the class. The students were asked to choose from the twelve assignments as they felt comfortable. Therefore each group of students was working on a different problem and did not feel challenged by neighboring groups that might have been working faster. The advantage of teaching in small groups was that individual problems were solved and questions of different levels were answered by speaking to the students directly and personally. The needs of the different groups were met directly and -most important- individually which helped the students to progress successfully. To keep the level of noise tolerable each group received colored cards (green: everything is going well, yellow: we need some guidance, red: urgent question). These had to be placed visibly onto the tables so that the lecturer could set priorities which group to work with without disturbing others. Only if the assignment was solved and discussed successfully with the lecturer the group proceeded to the next assignment. Groups that worked steadily and quickly were allowed to leave as they wished (most stayed until the last minute). Remaining groups had the opportunity to go into more details and have questions answered that were still open. After studying the teaching material and attending hands-on session students felt well prepared for a test counting 5 out of 60 points

Iron carbon phase diagram

The equivalent method was used to introduce the iron carbon phase diagram (basis of steel production). Because extended knowledge on phase diagrams could be presupposed the iron carbon phase diagram was challenging but much easier for students to understand. In class phases and microstructures important to understand cooling and heating procedures of steels were described in detail. Homework assignments were eleven lecture films on how to read the iron carbon phase diagram and generate microstructures as a function of carbon content. These lectures were also filmed in SS 2015 summing up to approximately 2:45 hours. Additionally two lectures were assigned which demonstrated microstructures of various steel qualities helping students to relate theory of crystal growth and microstructure with the actual engineering material. Instead of another present lecture an extended homework assignment comprised of cooling curves, crystallography and structural behavior of iron carbon alloys was given to the students. Online forums allowed for discussion in closed working groups and extra explanation by the lecturer if needed and requested. Both lecture films and homework assignment were directly prepared for an evening online test the following week.

Results

Both lecture units, phase diagrams and the iron carbon phase diagram were assessed by online tests accounting for 4 out of 60 grade points of the material science introductory course (Pfennig, 2017).

Assessment of Students' Learning Outcome

General phase diagrams

A compulsory test (40 questions in 60 minutes) had to be taken via Moodle at the end of the following week and results showed clearly that students had a much better understanding of how to work practically with phase diagrams and related problems compared to results of the end of term exam the previous semester. 45% of the students scored very good or excellent in winter semester 2015/16 and even 70% scored very good or excellent in SS 2016 (Figure 3). Part of the better results in later semesters might due to better succession of the inverted classroom scenarios.

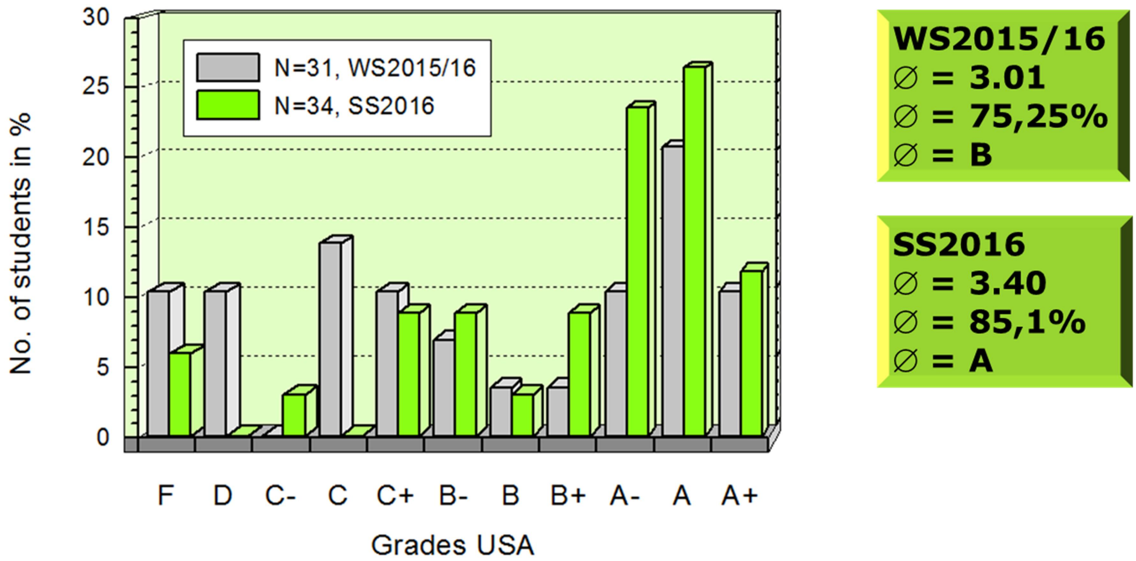

Figure 3. Results of compulsory online exam on phase diagrams.

In the final exam of summer semester 2015, students solved 43% of the phase diagram related problems correctly (Figure 4, left). In SS2015 phase diagrams were taught in-front. The following semester (winter semester 2015/16) phase diagrams were taught by the inverted classroom approach and 68% of the problems related to phase diagrams were solved correctly (Figure 4, right). Here, the greater percentage may directly be related to the teaching method with students being deeply involved in their own learning progress and having taken responsibility of their learning outcome.

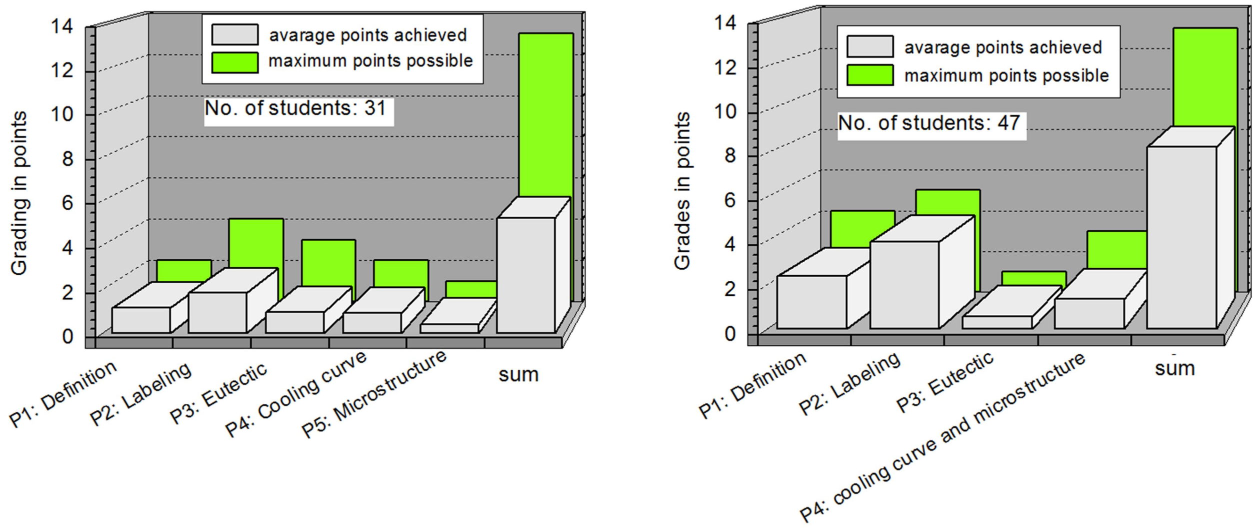

Figure 4. Results of compulsory online exam on phase diagrams, left SS2015, right WS15/16

Iron carbon phase diagram

A compulsory test had to be taken via Moodle after the completion and discussion of the homework assignment a week after the face-to-face session. In agreement with previous outcome on phase diagrams results clearly showed that students had a good understanding of how to read and interpret the iron carbon phase diagram. They also knew how to divide steel classes by microstructural phenomena and relate mechanical properties to carbon content and microstructure. In summer semester 2016, this test could be taken voluntarily but in in winter semester 2016/17, it was compulsory (Pfennig, 2017). 50% of the students in summer semester 2016 and 81% in winter semester 2016/17 scored excellent (Figure 5). Results were much better when the test was mandatory, because the students showed good motivation and prepared themselves well during the self-studying phase. There is no comparison to results obtained after the iron carbon phase diagram was taught in-front. However, the good results show strong evidence that inverting the classroom got students` attention and improved the overall grades.

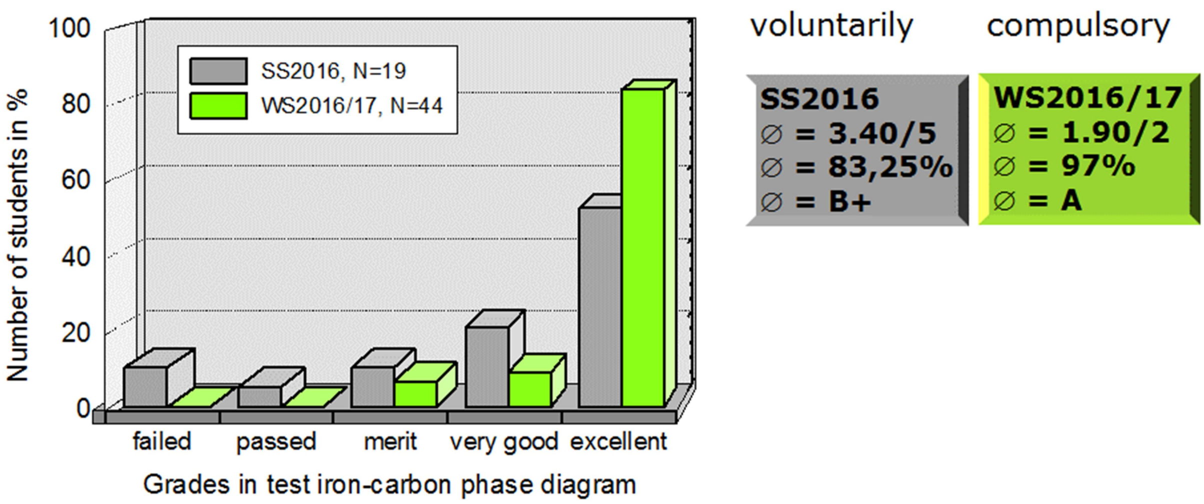

Figure 5. Results of compulsory online exam on the iron carbon phase diagram.

Evaluation of lecture videos

Since lecture videos are the "heart of teaching materials" in an inverted classroom scenario there is much interest in the evaluation of the students` opinion, their study progress related to lecture videos and their learning outcome. Therefore, quantitative data were collected to explore the following research questions:

1. Does the length of the video influence the study behavior?
2. Does the length of the video influence the number of repetitions of a lecture video?

Overall, students rated the class as successful (68%-73% rated good or excellent) both in terms of learning output and good study atmosphere in class. Most students rate the repeatability of the video lecture units beneficial. 80% state that videos of lectures may completely replace lectures in presence; only 12% believed that their study progress will only be enhanced in class. None of the lecture films was defined as the best or the worst with students watching one to all lecture films. Lecture film "Introduction" and "phase diagram with complete solubility" were defined as "easy to follow". All lecture videos appeared equally beneficial regarding the individual learning process. This represents the diversity of the class and shows that none of the subthemes is liked the most. It is remarkable that many students (137) clicked on the entire lecture film (2 hours and 35 min.) and watched an average of 20 min. (ca. 15%) before deciding to go with smaller units.

Some students criticized that during some film minutes board and viewgraph could not be seen together; so, they had difficulties bringing the lecture in order (although viewgraphs were downloaded before the assignment). A good suggestion was to focus on the writing more than on the lecturer during filming. The time slot for phase diagram lecture film preparation was asked to be 14 days and not as is has been here only 7 days.

The author wants to point out that no significant relation between number of clicks and length of the lecture films was analyzed (Figure 6).

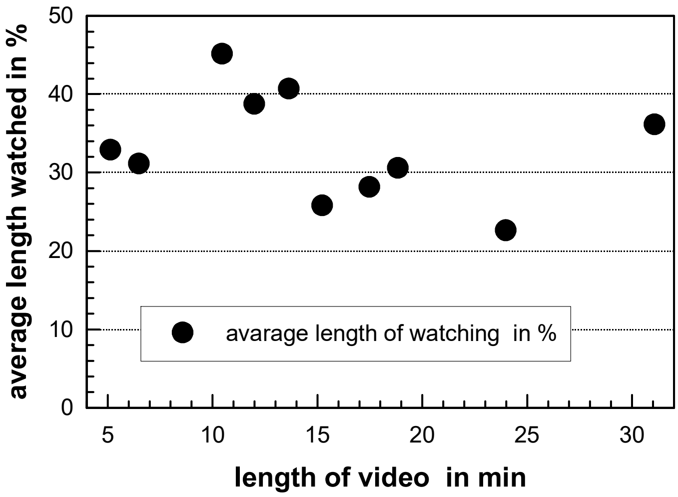

Figure. 6. Average time in % of students watching lecture films in WS2015/16.

The same applies for the time a lecture film was watched as a function of its total length (Figure 7). That means that the length of lecture films has no influence on the study behavior of the students. Moreover they decide on their individual needs and interest when watching and studying videos.

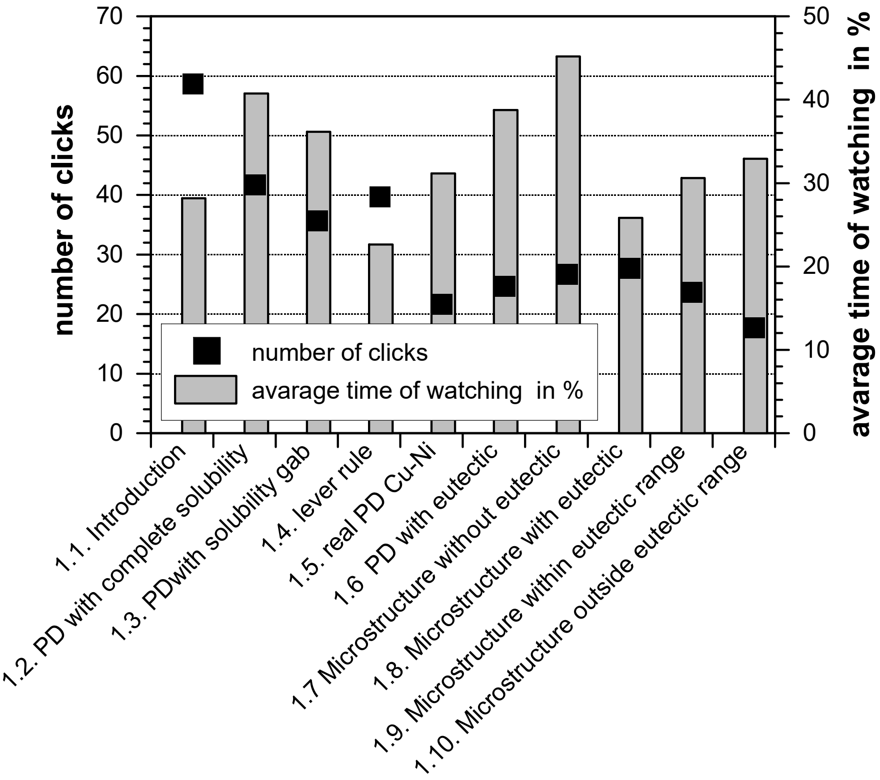

Figure. 7. Clicks and average time in % that students watched lecture films as a function of lecture film unit in WS 2015/16, inverted classroom scenario.

Same findings account for statistics of lecture films on the iron carbon phase diagram: no significant relation between number of clicks and length of the lecture films was analyzed (Figure 8). However, although 54 students were assigned in this class, only approximately 35 students came to class regularly and by the end of the second semester 20 dropped out. It is remarkable that from Figure 8 it may be assumed that each of the students passing the first semester at least watched all the lecture films on the iron carbon phase diagram once regardless of the length of the individual video. The complete lecture film (2:45 hours) was clicked on more than 80 times, but only watched 18% because the individual chapters were much better to handle. Averagely approximately 45% of most lecture films were watched meaning that students may not have finished all the way. Note that statistics also comprise those misclicks where students accidently chose the wrong lecture film and shortly after the beginning closed the film again. This adds to the small average length of time a lecture video was watched.

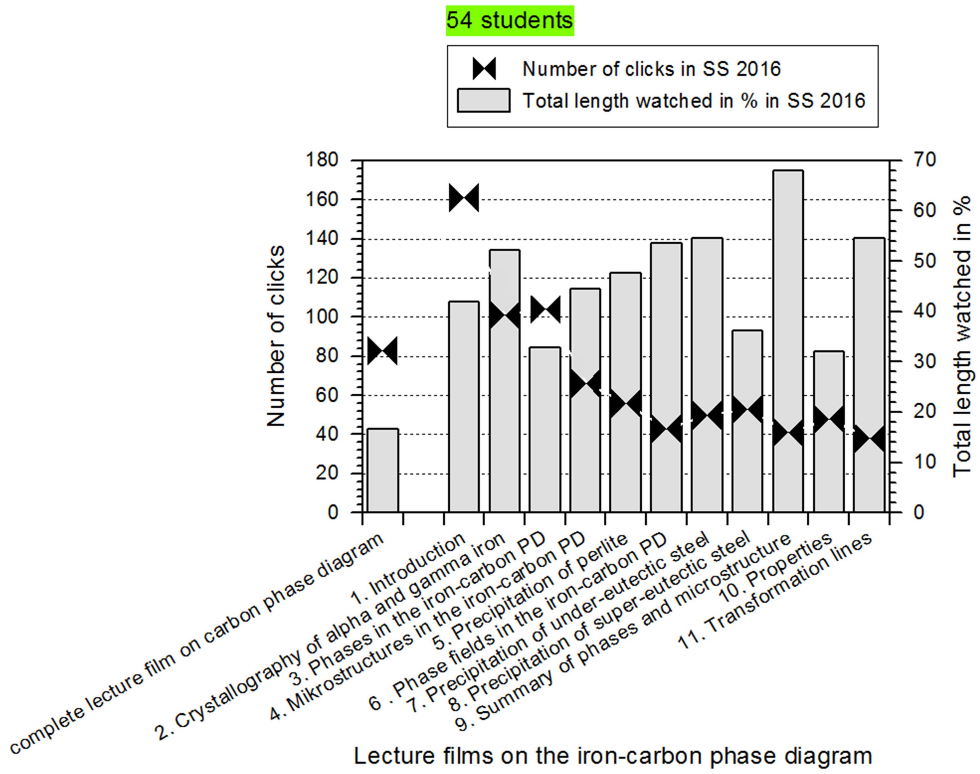

Figure. 8. Clicks and average time in % that students watched lecture films as a function of lecture film unit in SS 2016, inverted classroom scenario.

Discussion

All in all, the lecture concept „inverting the classroom" with self-studying based on videos of class lectures was rated positively. Students were eager to work on problem solving in small groups and present their results to the class. 70% of the students brought notes on the lecture films into class showing their serious study period at home helping with the hands on problems in class. Depending on their state of learning students individually chose lecture videos, number of repeats of the same video and the length of time they kept watching continuously.

Lecture videos as main source of the "inverted classroom concept" are independently reusable once generated and provided. They apply well in the today`s students' way of achieving skills. The independence of time and place of the individual lecture in combination with the possibility to repeat whole lectures as well as small parts helped to meet the individual learning velocity of the students. During self-studying, students were very motivated to learn, then share their knowledge helping others and contributing to solving problems in class. The pleasant atmosphere in class enabled students to apply their knowledge and solve material science problems. Small groups allow for individual explanations and personal contact to students. If both students, who are producing lecture films as well as those learning through them, are given more responsibility for their learning progress, their critical thinking skills will be encouraged (CSU, 2015, Lord, 2012); resulting in deeper learning outcomes (Goto and Schneider, 2010, Simon et al., 2010).

There is always the chance of losing students who are not willing to study at home in the long run, first because of lack of background knowledge, second because they are not able to contribute to group or class work or work on assignments independently. Therefore it is always necessary to be prepared for groups that may not be able to work properly in class. Because the assignment was clear, there is no time for lecturers to let them catch up in class. But, because peers are sitting next to them, the author`s experience was that these students prepared themselves very well after the contact time and achieved good grades. In general, the same number of students (35 out of 44) visited the classes regularly compared with the courses taught the traditional way. Time spent studying before class (approx. 4h-5h) in the inverted classroom environment compares to the time estimated for studying after class when taught in-front. 4h-5h of studying phase diagrams in material science are necessary to understand and get good grades according to the students.

The method of “inverting the classroom” was assessed as beneficial in terms of student grades, concentration and attentiveness as well as joy of studying. Students took over responsibility for their own learning process and generally achieved better grades than those taught in “front classroom” scenarios. Still, evaluation over a long period of time has to prove in future, if this concept will enhance students` material science skills and grades in general.

Conclusion

In order to obtain substantial learning output on the difficult subject: phase diagrams the "inverted classroom" teaching method was introduced to first year mechanical engineering students in a material science course. Therefore micro moodle-based online lectures, lecture films, screencasts, lecture slides and various teaching material were provided along with a distinct assignment for one week and regular graded tests and assignments. In class the students focused on discussing scientific backgrounds and solving hands-on problems relating to phase diagrams and the iron carbon phase diagram in groups of 2 to 4 students. Inverting the classroom involved students to take over the responsibility for their own learning process and the method was assessed as beneficial in terms of student grades that were significantly improved in an inverted classroom environment. Also concentration, attentiveness and joy of studying were considered superior. Lecture films apply well for students' way of achieving skills and were rated advantageous because of the possibility of independent reuse meeting the individual learning velocity of the students.

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References

Ashby, M., Shercliff, H., Cebon, D.(2013). *Materials Engineering, Science, Processing and Design*, 2013: ISBN-13: 978-0080994345, 2013: ISBN-10: 0080994342, Pub date: Oct 02, 2013 (3rd edition).

Berrett, D. (2012). How 'flipping' the classroom can improve the traditional lecture, *The Cronicle of Higher Education* (2012, February 12). Retrieved from http://www.chronicle.com/article/How-Flipping-the-Classroom/130857

Brame, C.J. (2015). Flipping the Classroom (2015, September). Retrieved from http://cft.vanderbilt.edu/files/Flipping-the-classroom.pdf.

Braun, I. et al. (2012). Inverted Classroom an der Hochschule Karlsruhe - ein nicht quantisierter Flip, Beitrag zu „Das Inverted Classroom Model: Begleitband zur ersten deutschen ICM-Konferenz“, Jürgen Handke, Alexander Sperl (Hrsg.), erschienen im Oldenbourg Verlag.

Colorado State University (2015). Using Peer Teaching in the Classroom. Retrieved from http://teaching.colostate.edu/tips/tip.cfm?tipid=180.

Educause Learning initiative (2016). THINGS YOU SHOULD KNOW ABOUT…™ FLIPPED CLASSROOMS. Retrieved from https://net.educause.edu/ir/library/pdf/eli7081.pdf, call: 01/2016.

Fischer, M und Spannagel, C (2012). Lernen mit Vorlesungsvideos in der umgedrehten Mathematikvorlesung, in Desel, J., Haake, J.M. und Spannagel, C. (Hrsg.), DELFI 2012, Die 10. E-Learning Fachtagung Informatik der Gesellschaft für Informatik e.V., S. 225-236, Bonn: Köllen Druck + Verlag, Copyright © Gesellschaft für Informatik.

Goto, K. & Schneider, J. (2010). Learning through teaching: Challenges and opportunities in facilitating student learning in food science and nutrition by using the interteaching approach. *Journal of Food Science Education* 9 (1), 31-35.

Invote (2016 June). Retrieved from http://invote.de/

Lord, T. (2012). 101 reasons for using cooperative learning in biology teaching. *The American Biology Teacher* 63 (1), 30-38.

Online Lehre Plus / external fund: Berliner Qualitätsoffensive für die Lehre (2016). https://www.berlin.de/sen/wissenschaft/wissenschaftspolitik/finanzierung/vereinbarung_berliner_qualitaetsoffensive_fur_die_lehre_2012_bis_2016.pdf.

Qualitätspakt Lehre – Teil-Projekt „excelLuS“ HTW-Berlin (2016). "Studieren an der HTW Berlin – exzellente Lehre und hervorragender Service", Förderprogramm "Bund-Länder-Programm für bessere Studienbedingungen und mehr Qualität in der Lehre" des Bundesministeriums für Bildung und Forschung (BMBF) mit Förderkennzeichen: 01 PL 11034 und Förderzeitraum vom 01.11.2011 - 30.06.2016.

Schumann, H. (2010). Metallographie, Leipzig: Deutscher Verlag für Grundstoffindustrie GmbH, Leipzig 1991, 1990. 13. Auflage 2010.

Simon, B., Kohanfars, M., Lee, J., Tamayo, K, & Cutts, Q. (2010). Experience report: peer instruction in introductory computing. *Proceedings of the 41st ACM Technical Symposium on Computer Science Education*, 341-345.

Pfennig, A. (2017). Improvement of learning outcome in material science through inverted classroom techniques and alternative course assessment. 3rd International Conference on Higher Education Advances, HEAd´17, 23-25 June 2017, València, Spain.

Pfennig, A. (2016). Inverting the Classroom in an Introductory Material Science Course. *Procedia - Social and Behavioral Sciences*, 228, 32-38.

Pfennig, A. and Hadwiger P. (2016). Peer-to-peer lecture films - a successful study concept for a first year laboratory material science course. *Procedia - Social and Behavioral Sciences*, 228, 24-31.

Pfennig, A. and Böge, A. (2015). A material science course based on a blended learning concept using an interdisciplinary approach at HTW Berlin. "e-Learning'15", 11-12 September 2015, University of Applied Sciences, Berlin, Germany.

Fingerson, L. & Culley, A. (2001). Collaborators in teaching and learning: Undergraduate teaching assistants in the classroom. *Teaching Sociology*, 29(3), 299-315.

Cuseo, J.B. (1992). Tips for students when forming learning teams: How to collaborate with peers to improve your academic performance. *Cooperative Learning and College Teaching*, 7(3), 11-16.