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Flipped classroom – a solution to teach the unloved iron carbon phase diagram in first year engineering during the Covid-19 pandemic

Anja Pfennig
School of engineering and life science, HTW Berlin, University of Applied Sciences, Wilhelminenhofstr.75A, 12459 Berlin, Germany.

Abstract
The iron carbon phase diagram ICPD may simply be described as alloying maps of steels and cast iron in material science. However, the required thermodynamic background knowledge should be high level and understanding of the cooling procedure of ferrous melts as well as microstructure of steels is challenging. Common teaching material presents results, but not how to get there and leaves frustrated first year engineering students behind – especially during the online-semester of the Covid-19 pandemic. The iron carbon phase diagram is required in advanced courses, but seldom handled by students. Applying the "flipped classroom" teaching method as scenario in a blended and fully online learning environment is shown to be a successful method to let the students study how to read and apply the ICPD on their own and then take the time to discuss their questions and do extended hands-on exercises in class. Although summative assessment did not show significant improvement, the learning outcome and problem solving skills related to the iron carbon phase diagram are rated beneficial.

Keywords: *iron carbon phase diagram, lecture films, inverted classroom, flipped classroom, blended learning, online teaching, first year students.*

1. Introduction to the teaching concept “flipped classroom”

Teaching according to the inverted classroom teaching concept 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: Pfennig (2018). The method is proved by many authors to successfully gain student`s attention, thus acquire good exam results: Berret (2012), Brame (2015), Pfennig (2018). Gulley et al. (2016) state that the understanding and retention of course material was improved along with effective use of time in class. It is widely reported that students take over more responsibility for their learning progress during the semester which is related to enhanced critical thinking: CSU (2015), Lord (2012). Inverting the classroom may even lead to deeper learning outcomes: Goto and Schneider (2010), Simon et al. (2010) and has a positive effect on self-efficacy beliefs and intrinsic motivation: Thai et al. (2017). However, Setren et al. (2019) indicate success for MINT courses but discuss minor to no advance when the flipped classroom teaching method is applied in economic related teaching.

The blended learning introductory material science course at HTW Berlin is taught to first year mechanical engineering students via the “design-led” teaching approach: Ashby et al. (2013), Pfennig (2018). While the conventional “science-led” teaching approach begins with the physics and chemistry of materials, progresses from the atomistic model 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: Pfennig (2018). This teaching concept implements distinct “inverted classroom scenarios” of suitable themes because learning skills and grades improved compared to front classroom teaching methods: Pfennig (2018), Pfennig (2021). Mostly lecture films as main learning resources: Pfennig (2019) to acquire scientific background are offered supported by a variety of teaching material such as micro module lectures, worksheets and worked solution, mind maps, glossaries, memory sheets, online tests and web-based-trainings wbt: Pfennig (2018). It is very important that certain criteria are met to successfully teach inverted: Pfennig (2021) and that students are guided well but at the same time able to study individually, self-directed, location-independent, asynchronously and according to their individual tempo. In class there is time to discuss problems (plenum), work on exercises and engineering related problems in small groups or break-out sessions. Students share difficulties and thoughts with neighbours and classmates discussing the background information acquired during self-study periods.

However, the covid-19 pandemic required to transfer face-to-face time into online-sessions and the important plenary session to fully understand the iron carbon phase diagram had to adapted to the online environment. This paper describes a teaching routine that enhances students`scientific knowledge, responsibility for the learning process, self-efficacy and the ability to solve engineering problems regarding steels and the iron carbon phase diagram.

2. The iron carbon phase diagram: home assignment and contact time

The iron carbon phase diagram ICPD and how to interpret, read and transfer knowledge onto real microstructures of materials seems to be an awful hassle for first year students. Due to the curricula, this theme has to be taught in first year engineering studies at HTW Berlin. The ICPD may simply be described as an alloying maps for steels (Figure 1, left). However, the required thermodynamic background knowledge is high level and understanding the cooling procedure of metal melts as well as microstructure of different steels (iron carbon alloys) is challenging. Common teaching material only presents results, but does not explain "how and why" - frustrating first year engineering students. The iron carbon phase diagram is required in advanced courses, but seldom handled by students. Therefore, it is much more conductive if students engage in practical work and team assignments (break-out sessions) transfering their knowledge rather than only listening and taking notes during class (online-lecture).

Self-studying was assigned via "Moodle" following the guidelines mentioned earlier: Pfennig (2021). Note, that we relate to lecture recording in this paper in contrast to lecture videos: Pfennig (2019). The 4-hour lecture on the iron carbon phase diagram was filmed and cut into 11 videos with distinct headlines, so that each student could easily navigate to understand how to read the iron carbon phase diagram (Figure 1). Additionally 2 lectures were assigned which demonstrated microstructures of various steel qualities helping students to relate theory of crystal and micro structure with the actual engineering material. An extended homework assignment comprised of cooling curves, crystallography and structural behavior of iron carbon alloys was given to the students. Moderated 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 as well as the following contact time directly prepared for an evening online test the following week.

During the online session (as well as in class) phases and microstructures important to understand cooling and heating procedures of steels were described in detail. The open-source software "invote": https://www.invote.de/ was used for class assessment: Simon et al. (2010), Pfennig (2018), to obtain an overview of the student`s knowledge. Students` questions were answered and important issues explained individually using a graphic tablet. Students were divided into groups of 4. 12 assignments of different levels were categorized into: 1.) pass the class, 2.) pass with C or B, 3.) pass with A or even better and provided via Moodle. The students were asked to choose as they felt comfortable. The advantage of teaching small groups was that individual problems were solved and questions of different levels were answered by speaking to the students face to face and meeting her or his needs. Group work was performed via break-out session but "wonder.me": https://www.wonder.me/ allows the lecturer for easier navigating from one group to another.

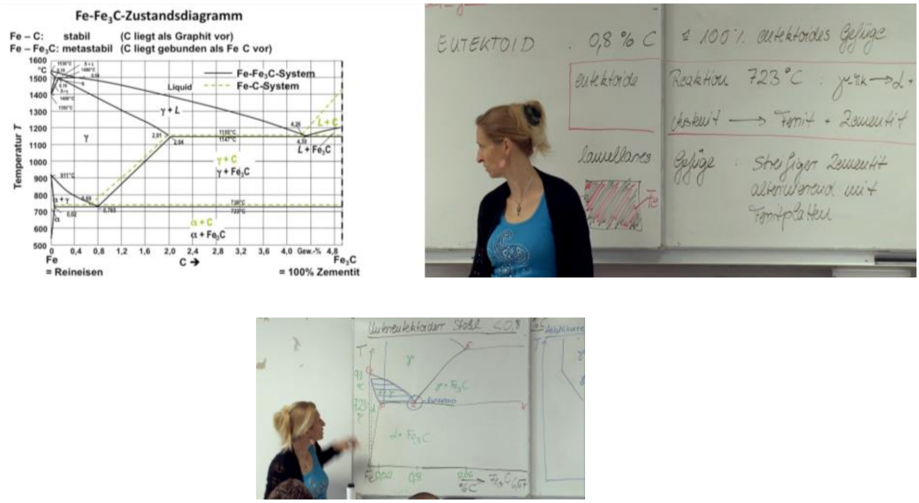

Figure 1. Lecture video: iron carbon phase (11 lecture films) (2:45 hours), (https://www.youtube.com/watch?v=_RdbQFk4jWU&list=PLUOlZMSZYz5yHjaqEAaPj77ignXqACXaD)

Up to 6 groups with their individual guiding requests may be handled well by the lecturer. With more than 25 students different session times were assigned. Students had enough time to work until they fully understood and were able to transfer knowledge correctly in an adequate time

3. Assessment of students learning outcome

A compulsory test adding to the total grade: Pfennig (2018) had to be taken via "Moodle" the following week. Results show clearly that students had a lot of difficulties during the Covid-19 pandemic compared to the previous semester where the small group work was conducted during face-to-face time (Figure 2). Note that in SS2020 the hands-on problems were solved in the online plenum (red) and the small group work was moved to break-out session starting SS2021 (orange). Gathering students in small online-groups in SS2021 leads to a much better understanding how to work practically with the iron carbon phase diagram compared to results of the previous semester. Most students had a good understanding how to read and interpret the iron carbon phase diagram, divide steel classes by microstructural phenomena and relate mechanical properties to carbon content and microstructure.

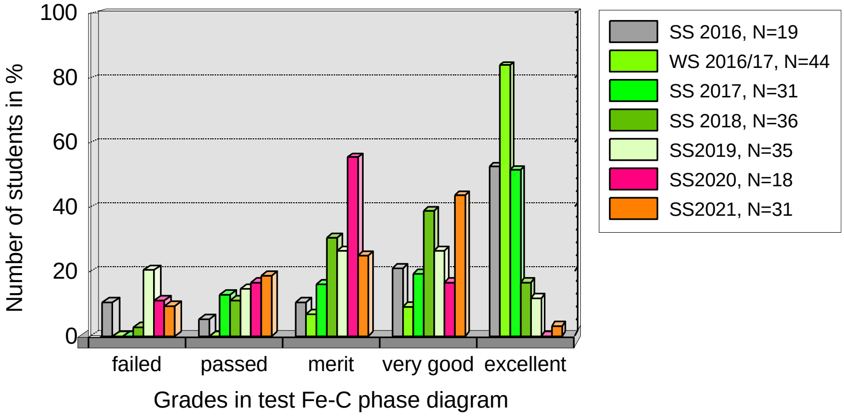

Figure 2: Results of compulsory online exam on the iron carbon phase diagram.

4. Evaluation of self-study period and filmed lectures

Overall students rated the implementation of the filmed lectures as helpful teaching material during the self-study period (65-78% rated good or excellent from summer semester 2020 to winter semester 2021/22). Both, recorded lectures as well as guided questionnaires support their learning process and increase learning output. The repeatability of the film lecture units is rated highly beneficial. After 3 mostly online-semesters only approximately 10% of the students appraise recorded lectures as replacement of lectures in presence; most of the students fear that their study progress will only be enhanced in class. (Note, when presence lecturing was allowed and offered less than 50% of the students showed!!!).

The length of the lecture recordings varied from 1 (crystallography) to 12 minutes (microstructures). The undivided recordings lasts approximately 2 hours and 45 minutes. It is remarkable that Figure 3 allows to assume that each of the students passing the first semester at least watched all lecture films on the iron carbon phase diagram once - regardless of the length of the individual video.

The complete lecture film was clicked on more than 80 times and watched an average of 20 min. (ca. 18%) before students decided to go with smaller units because the individual chapters are much better to handle. The 11 lecture recordings were averagely watched more than 50% 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 stopped shortly after beginning to watch the film. This adds to small average length of time watched.

No significant relation was found regarding number of clicks or total time the lecture recording was watched and length of the lecture recordings (Figure 3). Therefore, although generally 6 to 10 minutes are the preferred length lecture videos are chosen from the youtube channel and students rate appropriate in terms of attention, concentration and motivation: Pfennig (2019) the length of the recordings of the iron carbon phase diagram does not negatively influence the study behavior. Students decide according to their individual motivation, interest and need of content (or even expected assessment) when preparing recoreded lectures.

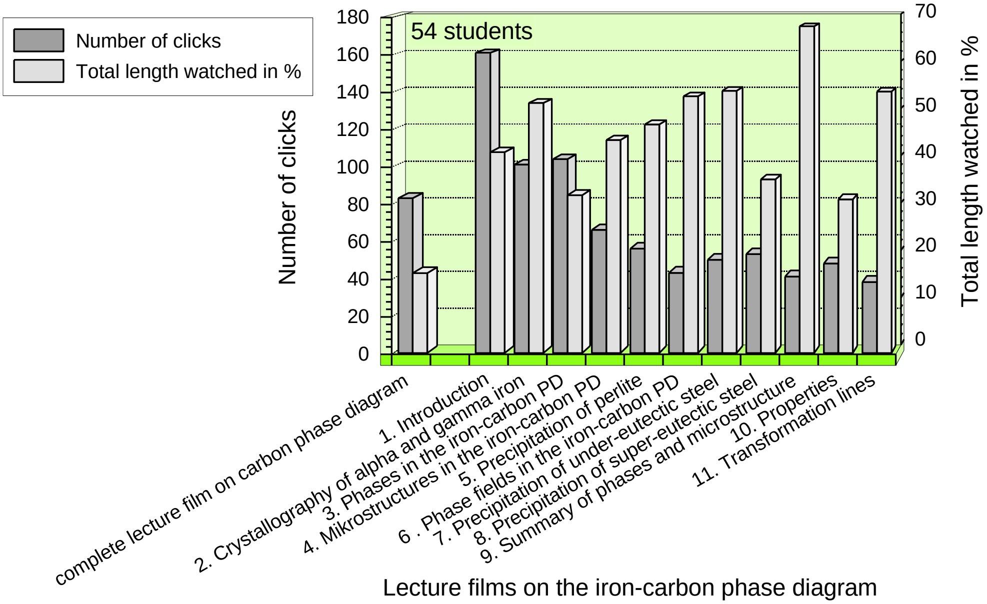

Figure. 3: Clicks and average time in % of students watching lecture recordings as a function of lecture film unit, inverted classroom scenario.

Because most of the students prepared all of the 11 video lectures without picking one particular as best or worst all lectures may be rated equally beneficial regarding the individual learning process. It may be assumed that ordering recorded lectures beforehand is of little to no relevance although some students criticized that during some film minutes whiteboard and slide could not be seen together. A good solution are lightboard videos (writing glass): Pfennig (2021-2) where the writing and explanation is focused on while students are faced directly.

5. Feedback on the "inverted classroom" concept in an online environment

Advantage of lecture recordings as main source of the online "inverted classroom concept" are their multiple independent reuse which applies well in the nowadays student`s way of achieving skills independent of the Covid-19 pandemic. Time and place independence combines perfectly with the possibility to repeat whole lectures as well as small parts and directly supports individual learning velocity. Despite general bias students worked concentrated within their break-out groups and were open and eager to present their results and discuss. The atmosphere in break-out sessions was described as cooperative and valued. The small groups allow for individual explanations and more personal contact to students. Therefore most important, students did not hesitate to ask questions and stayed focused until they were satisfied with their output. With help of guided self-study period students seize their chance to take responsibility for their learning progress early which encourages critical thinking: CSU (2015), Lord (2012) and results in deeper learning outcomes: Goto and Schneider (2010), Simon et al. (2010).

The loneliness, insecurity and boredom of remote self-study period without contact to fellow students challenges you people tremendously. Even with close guidance students will be lost in inverted teaching, because firstly inability to acquire scientific background knowledge and secondly insecurity to participate during small group work due to personality, group constellation or nescience. Some students have severe difficulties to work on assignments independently at home without the possibility to reassure with fellow students. Lectures need to take into account these various difficulties and that students might be unprepared but at the same time willing to work during break-out sessions. Encouraging these students to participate, working with them for a couple of minutes reassures them that they may contribute well to the group – even with hardly time to repeat content required during self-study period. Posting questions for all students using for example “padlet” or “miro-board” helped students to feel as part of the community and start discussions among them early. The assigned group homework –comprising of highly advanced problems- was solved nearly 100% correctly with only minor mistakes that were discussed in a following online session.

The “flipped classroom” method to teach the iron carbon phase diagram was assessed as beneficial in terms of students` responsibility of their learning process, concentration and attentiveness as well as joy of studying but not necessarily in terms of grades. However, the self-study period needs to be guided close and students exactly need to know what and especially why to prepare the lecture recordings. To let them know the procedure during the online-session and expected common work in a forum or “padlet”, presenting results or posting and answering questions is vital for student motivation during self-study periods. “Feeling lost” was the feared emotion during the Covid-19 pandemic. Lecturers may emasculate these negatively connotated emotions by showing students the importance of their well-being and good performance during self-studying and in online-lectures.

Note, that the time to prepare necessary Moodle activities connected to the iron carbon phase diagram meeting the needs of a diverse first year material science class remains high and the workload approximately doubles. It is worth though, because the material may be reused every semester due to the immutable content. Contact time outside the classroom/online-session increases in online-semesters due to extra explanations. Also, students need to be reassured that they are doing well or they simply need to stay in contact. Still, positive student feedback and joy of teaching accounts for the flipped classroom method even with first year students and a topic rated very complicated by mechanical engineering students.

6. Conclusion

Implementing the inverted classroom approach also in a fully online teaching environment is successful in terms of learning outcome and problem solving skills related to the iron carbon phase diagram, but not in terms of improving grades. Still, the teaching method clealy enables students to work self-reliantly in comparison to traditional teaching. One factor of success is a close guided self-study period with diversified learning material transparent tasks, time line and expections for the following online-session. Another factor is the calm enforcement of the online-session focusing on students ability to learn and transfer engineering problems at the same time. Although preparation time increaes the positive and more sustainable learning outcome is worth the effort.

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