Improving Learning Outcome in Material Science through Inverted Classroom Techniques and Alternative Course Assessment – a case study

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Abstract: Material Science is known to first year mechanical engineering students as one of the fundamental courses with high work load. The knowledge of the complex science of materials enables students to select appropriate engineering materials in different designs due to acquired knowledge on the correlation of materials properties, microstructure and their intended manipulation. These abilities are not well constituted in one final exam. Therefore peer-to-peer lecture film supported inverted classroom scenarios were established to work in the course. These were accompanied by a newly developed Moodle course following the blended learning approach that gives students the chance to cumulative accomplish micro-grades via multiple activities, such as tests, lectures, presentations, forum discussions, written homework and glossary entries. These grades are summed to obtain the overall course grade. An improved learning outcome is demonstrated in high quality class discussions and most -important to students- in better grades (average 43/60=B) compared to those being assessed by one final exam only (average 39/69=C+). The majority of students agreed on enhanced study skills when forced to study throughout the entire semester instead of learning intensely towards the end of the semester. This case study introduces the learning structure as well as graded activities, qualitatively evaluates the course and semi-quantitatively compares activity results to former class results.

Keywords: material science, lecture films, peer to peer, inverted classroom, blended learning, first-year students.

Introduction to grading in higher education

Grading and reporting on student learning continue to challenge educators. To develop grading and reporting practices that provide quality information about student learning requires clear thinking, careful planning, excellent communication skills, and an overriding concern for the well-being of students (Guskey, 2012). Criteria-based approaches to assessment and grading in higher education is widely and controversially discussed due to its educational effectiveness but lack of common understanding in practice. But shifting the primary focus to standards and making criteria secondary could lead to substantial progress (Sadler, 2005). The educational benefits of standards-based versus the traditional score-based grading have been quantitatively modeled by Marbouti (2016) showing that standards-based grading is based on "the measurement of the quality of students' proficiency towards achieving well defined course objectives" (Heywood, 2014, p. 1514). Because standard-based grading assesses students' achievement of the course learning objectives, it provides clear, meaningful, and personalized feedback for students related to achievement of the course learning objectives and helps them identify their weaknesses in the course (Atwood & Siniawski, 2014).

Introduction to the first semester course material science in mechanical engineering at HTW

Material Science is taught as a compulsory course during first semester undergraduate study subjects such as mechanical engineering, automotive engineering and economical engineering at HTW Berlin based on the "design-led" teaching approach (Ashby et al., 2013), exceLlus, 2016), Pfennig, 2016-1, Pfennig, 2016-2) (Figure 1). The motivation to establish this route -especially in the first year of studying- was to involve students right from the beginning of their studies with the question 'What is the objective of the design? Students begin to investigate and learn with a strong practical motive and critically discuss materials, properties, alternative materials and processes as well as the underlying physics and chemistry. In the conventional "science-led" teaching approach begins with the physics and chemistry of materials. It progresses from the atomistic through the microstructure to the macroscopic properties. As a consequence the motivation by the challenges of the design is often lost. Still, it is necessary to understand the theory of material science, but the teaching goal should be to educate students and prepare them for their role as a maker of things (Ashby et al., 2013).

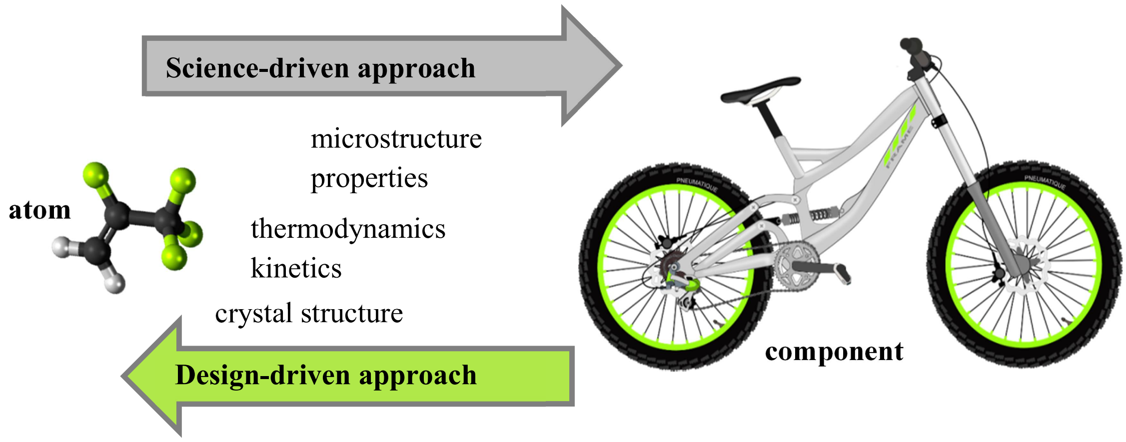

Figure 1. Science-led-approach and Design-led-approach modified from Ashby et al. (2013) (Molecule model taken from Wikimedia commons 2015, bicycle taken from http://www.hobbymarkt.com/fahrradshop 2015).

Teaching in "inverted classroom" scenarios (Berret, 2012), Brame, 2015), Fischer and Spannagel, 2012), Braun et al., 2012, Pfennig, 2016-1) is a method to let the students study the science on their own and then take time to discuss their questions leaving time to work on extended *hands-on* lectures or exercises in class. Peer instruction (Simon et al., 2010) is used to assess the learning progress prior to each class. The method of *blended learning* was found to apply well. Scientific peer-to-peer lecture films (OLP, 2016), Pfennig, 2016-1), Pfennig, 2015-1) and micro module lectures provided via content management system Moodle are the main learning resources. In addition different teaching materials e.g.: worksheets and worked solution, mind maps, glossaries, memory sheets, online tests and web-based-trainings wbt are available (Pfennig and Böge, 2015, Pfennig, 2016-1). Because different learning styles are considered students coming from different scientific and ethnic backgrounds are enabled to study during online periods in equal measure. In class there was time for *hands-on* exercises, discussions, group work and mastering difficult questions. These learning materials were partly contributed by students during material science projects (peer-to-peer approach (Colorado, 2015) and colleagues. This peer reviewing (Ware, 2015), Wilson, 2012) allows for high teaching standards (Pfennig, 2016-1).

Case study

The aim of this case study is to demonstrate how the inverted classroom method in alliance with a theme tailored decentralized grading system may enhance the learning outcome of first year mechanical engineering students. In this context the assessment of students` learning outcome on one single final exam as usual does not strike as appropriate. The grading system chosen directly connects the course assessments to the course learning objectives and are not only a series of separate course assignments as feared by Carberry et al. (2012). Although this case study does not aim at generalized fact based research outcome but rather points out alternative teaching methods in engineering environments qualitative and quantitative data were collected to explore the following research questions:

1. How do students respond to inverted classroom teaching scenarios?
2. How do grades change?
3. Does the decentralized grading system apply to students` learning behaviour?

Methodology - A new course structure and grading system

It was therefore necessary to decentralize the course assessment and establish step-by-step grades with regard to the learning objectives over the 12 to 16 weeks of the semester. Moodle provides an excellent basis to establish graded activities that follow each lecture or theme (Figure 2). All semester activities count to 50 points, the final *Moodle-exam* based on tests during the semester counts for 10 points (in sum 60). Therefore the following activities were weighted appropriately and implemented as compulsory summing to 60 possible points in total:

- 3 Quizzes = 12 questions (each 1)
- 9 Medium tests 20-40 questions (each 2)
- 1 Final test (70 questions) (10)
- 4 Glossary entries (each 1)
- 14 graded lectures (each 3 to 5)
- 3 homework assignment (each 2)

- 2 Forum entries (each 2)

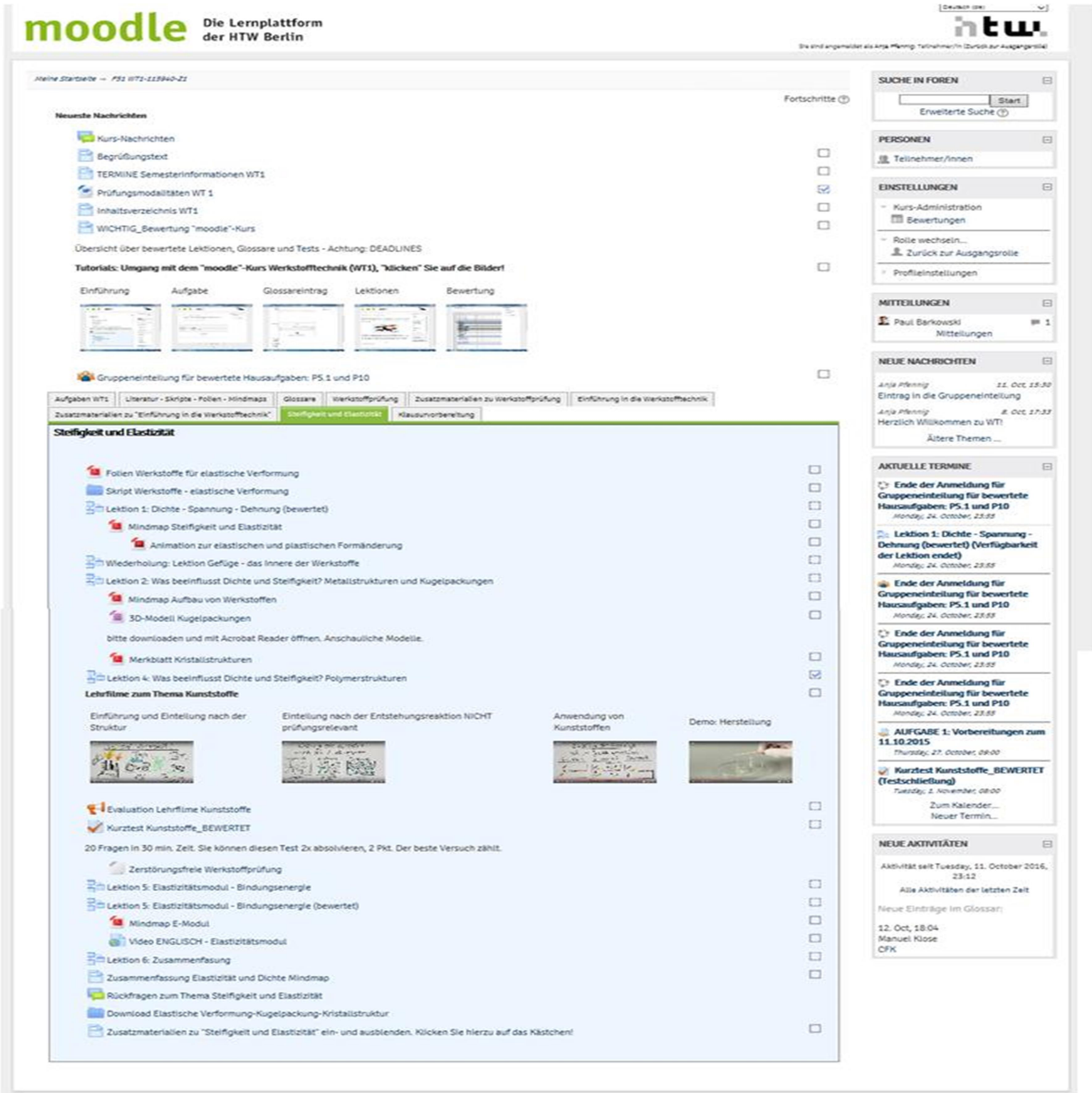

Figure 2. Example of Moodle course, theme: stiffness and elasticity.

Alternatively the students could choose to take a final exam isochronal to the final Moodle course test worth also 60 points (Figure 3). One week prior to the final exam the students had to decide by signature whether they wanted to be assessed based on their Moodle results of take the final exam. Students found this advantageous because they could make their choice the last minute depending on their grade points until the time of the final exam. To prevent students from stopping to work in the middle of the semester most of the points were assigned in the last 3 weeks before final exam (60 points) or final Moodle exam (10 points). The final exam counts for all students transferring in the middle of the semester, repeating students and those coming from different study subjects without access to present hours. Table 1 shows a rough outline of the course structure in summer semester 2016. Presence time was 1 day, 4 hours/week. HTW regulation allows for 20% e-Learning in a presence course, therefore the blended learning concept applies well. Contact during online phases was ensured via Moodle, chats and e-mail.

Table 1. Rough outline of materials science course structure.

Week	Theme	online/ presence	Homework	Main graded activity
1	Materials families	online	properties	2 micro lectures
2	Properties	presence	micro structure	1 micro lecture
3	Elasticity and stiffness	presence	crystalstructure	homework, test
4	Elasticity and stiffness	online	Youngs mod.	Test, glossary, lectures
5	Strength and ductility	online	lattice defects	Test, 2 micro lectures
6	Strength and ductility	presence	stress-strain	homework, 1 l lecture
7	Strength and ductility	presence	manipulating strength	Test, glossary, 2 microlectures, forum
8	Phase diagrams	online	Lecture videos	homework
9	Phase diagrams	presence	binary PD	test
10	Nomenclature	presence	materials	Homework, glossary
11	Fe-C phase diagram	presence	ECPD	Test, glossary, forum
12	Heat treatment of steel	presence	heat treatment	2 micro lectures, test
13	Steels and cast iron	presence	steels groups	prepare for final test
14	Final (moodle) test		mat. Science 1	final test

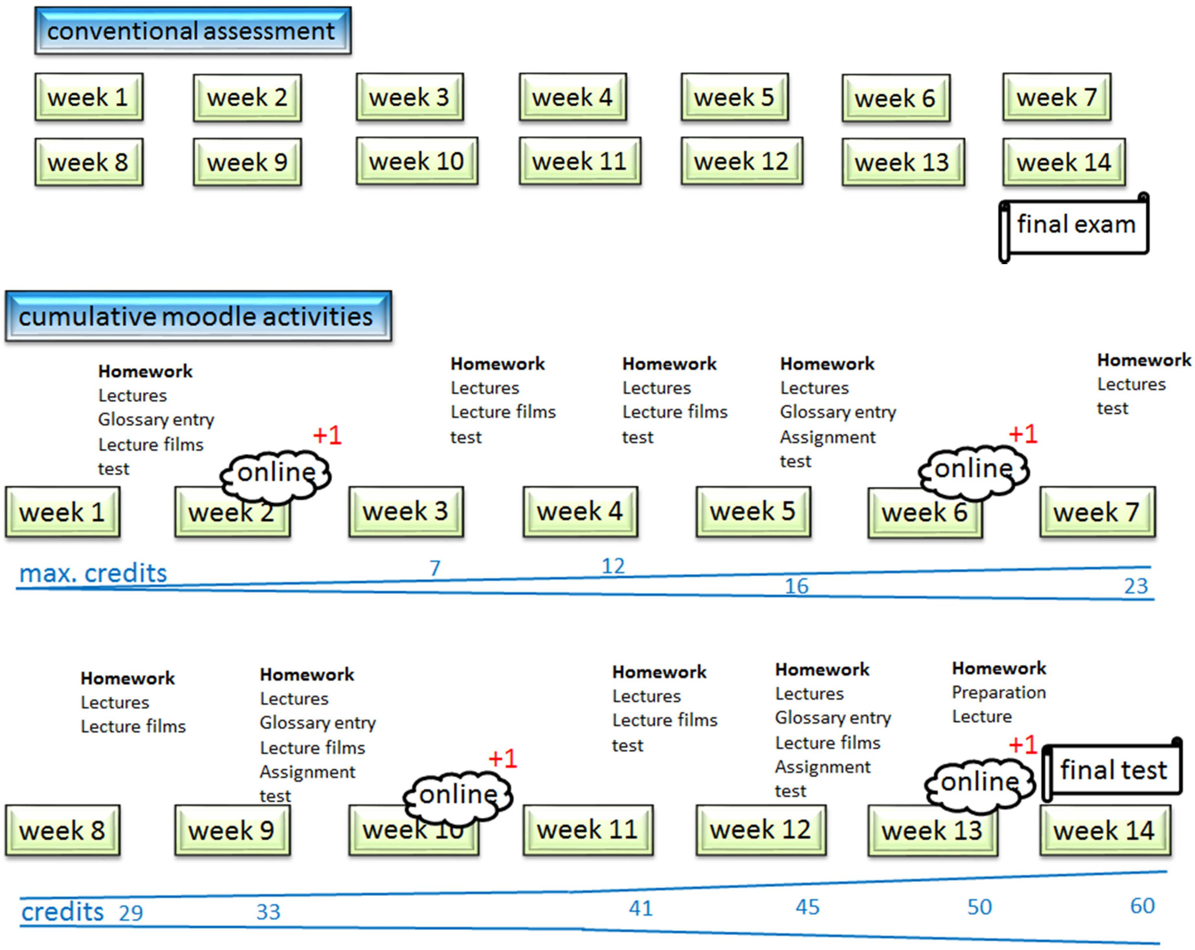

Figure 3. Workflow, Grading and Assignments in the one semester 4 hours/week Moodle based materials science course in comparison to the conventional teaching method.

Results and discussion

Example 1: Results of problem on phase diagrams in final exam

In summer semester 2015 the Moodle course was still an “add-on”. Students found study materials and were able to take voluntary tests. In winter semester first activities counted for extra grade points and were compulsory to access the final exam. The same problem on phase diagrams was given to students in both semester. This problem aimed at solving practical problems during the alloying of metals where phase diagrams had to be interpreted and used in the correct manner. Similar problems were given to the students in winter semester 2015 after studying the theory at home, but in summer semester phase diagrams were taught in class. In the final exam students scored 43% averagely of the phase diagram related problem in SS2015 where no inverted classroom scenario was applied and 68% averagely in SS2015/16 where phase diagrams were taught using the inverted classroom approach (Figure 4).

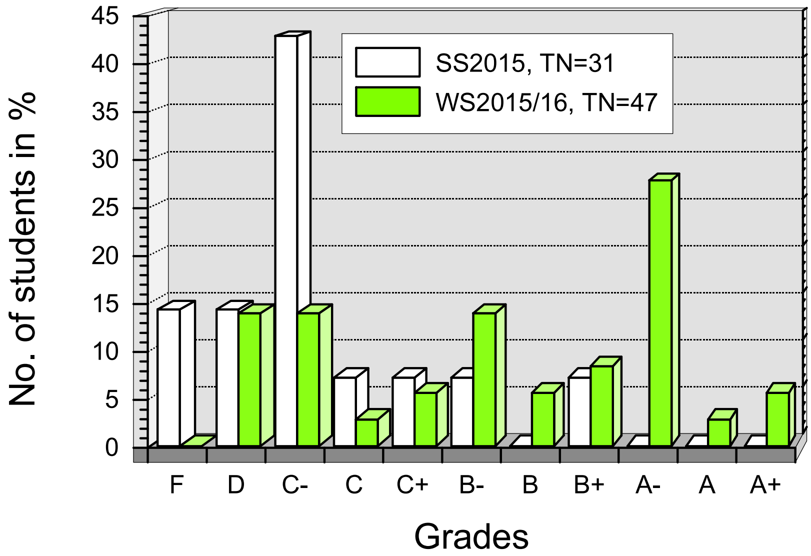

Figure 4. Results of compulsory problem on phase diagrams in final exam, left SS2015 (front teaching), right WS15/16 (inverted classroom). Purposely for reason of comparison the problem was the same in both semester.

Whether students of the summer semester 2016 had better natural abilities or studied better could not be evaluated. However, results showed clearly that students had a much better understanding how to practically work with phase diagrams compared the previous semester (Figure 4). Moreover, the results demonstrate that students were used to work properly throughout the semester and that the micro modules during the semester helped to build the bigger picture.

Example 2: Comparing course results with final exam and cumulative Moodle course assessment

Final grades in material science of winter semester 2015/16 -requiring a final exam in the end of the semester as means of assessment- were compared to grades students achieved in the cumulative Moodle course of summer semester 2016 (Figure 5). Prior to this assessment students had to sign a form that their grade will be calculated from their results throughout the semester.

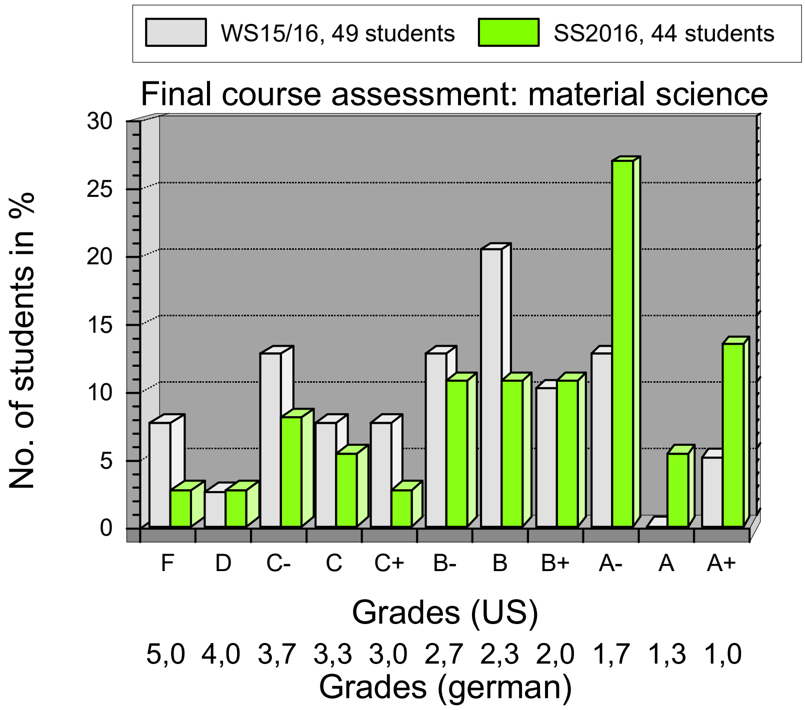

Figure 5. Results of compulsory final online exam in material science, left WS15/16, right SS2016.

Averagely students scored 39 (C+) out of 60 possible points in 2015/16 and 43 (B) (in 2016 (Figure 4). On first sight this does not count for massive improvement, but the median differs lot more: 43.5 (B) in 2015 and 49 (A-) in 2016. Still, most important is the grade distribution: The Moodle course assessment offers more students access to good grades, such as A- to A+ compared to the course assessment via final exam. Moreover, students with migration background scored higher and achieved better results than students belonging to the same group the previous semesters.

Discussion and evaluation of the Moodle course concept

The changes made in the first year materials science course for mechanical engineering students has not been performed at other universities or polytechnical schools in the described way. Therefore comparing results, learning outcomes and overall success of the methods can only be given from internal comparison.

In summer semester 2016 44 out of 52 students chose the course assessment via cumulative Moodle activities. 2 students chose a final exam and 6 students were lost during the first semester. Grades divided into more than 25 single micro grades that are weighed and summed offers the lecturer to be less biased during grading (CSU, 2015) and therefore students grades are more substantial. Both, accounts for this type of course assessment and the same process will be established in winter semester 2016/17.

Students` Opinion

Students found lecture videos and micro modules as main source of the “inverted classroom concept” appealing because they are reusable with no regard to place and time. The possibility to repeat whole lectures as well as small parts helped to meet the individual learning velocity. They found homework very useful in terms of self-organization and learning complicated scientific issues. Some students did not like homework, because they were forced to study instead of just pushing the work load ahead of them. Still, the biggest advantage of this grading system is the transparent level of points throughout the semester letting students directly know the grade they are achieving at the moment reassuring them of their learning skills. And even more important was the fact that the studying time did not push towards the end of the semester, but was equally distributed in time throughout the course. This allowed for more intense studying for other subjects at the end of the semester and focus on material science during the semester.

Teachers` Opinion

Pro: Because during self-studying students were very motivated to learn, they share their knowledge helping others and contributing to solving problems in class. The pleasant atmosphere in class enabled students to apply their knowledge solving even more complex material science problems. During the semester students were given more responsibility for their learning progress which encourages critical thinking: CSU (2015), Lord (2012); that results in deeper learning outcomes (Goto and

Schneider, 2010), Simon et al., 2010). It was fun teaching lively and critical students who were eager to enrich the material science class.

The depth of knowledge with which students responded in forums was very high. Students studied prior to answering or starting threads and posted facts as well as solutions for problems that were very well researched. In addition their discussion skills with regard to scientific knowledge were enhanced.

The possibility to work in small groups during class enables the teacher to provide help at the exact level the students learning has progressed and immediately supporting those who did not meet the requirements for a specific topic. Because the assignment is clear and most of the Moodle activities are available throughout the entire semester, unprepared students studied very well after the contact time and achieved good grades.

At-risk students that might fail the course could be identified very early and lecturers have the possibility to accompany their further learning progress more closely and –if necessary and wished- provide detailed guidance.

Students with migration background and language problems generally showed good to very good results in tests and assignment when they were given enough time to overcome their language problems. Because they had a chance to score high in this class we found that especially these students put a lot of effort into their studies. This reduced the diversity in learning outcome during the semester and assignments were worked on in a lot more homogeneous groups. Also, students who had to work or take care of family members could participate without knowledge loss, because the Moodle course offers time and place independent studying.

Contra: Students who only want to pass the course might not work constantly towards the end of the course once they achieved 30 points. It takes effort to motivate this specific group. However, increasing the amount of points adding to the course towards the end prevents students from dropping out early.

The amount of time to prepare Moodle activities necessary to generate a stand-alone Moodle course is outrageously high. The author is constantly working on lectures, lecture films and all other activities to improve learning outcomes and address all different learning types and meet the needs of a diverse first year material science class. Also, the time spent on emails answering question, giving advice or organizing has raised by a factor of 4 in addition to the time that has to be spent with the daily design of assignments etc. in the Moodle course. This adds to the extra time that is spent on correcting and commenting on assignments. To benefit from this new teaching method the workload of the lecturer does not double but honestly rather triples. All in all from a time perspective it is a lot less work to correct 50 final exams.

But students` positive opinions and the time spent in class voluntarily contributing to material science issues and the joy of working in class with enthusiastic students managing their own learning progress during a semester is worth the effort.

Conclusion

Material Science abilities are not well constituted in one final exam in a first year course. Therefore inverted classroom scenarios based on micro lectures and peer-to-peer lecture films were established and provided via Moodle The blended learning approach gives students the chance to cumulative add micro-grades via multiple activities, such as tests, lectures, presentations, forum discussions, written homework assignments and glossary entries. These grades are summed to obtain the overall course grade. Improved learning outcome is demonstrated in high quality class discussions and -most important to students- in better grades (average 43/60=B) compared to those being assessed by one final exam only (average 39/69=C+). The majority of students agreed on enhanced study skills when forced to study throughout the entire semester instead of learning intensely towards the end of the semester. Enthusiastic students were able to solve enhanced problems and contribute to many issues in more depth. In case lecturers do not hesitate to increase their semester workload this is a probate grading route to increase sustainable materials science knowledge.

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