Case Study: Flipped Classroom with Gamification in a Hybrid Fluid Mechanics Course

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A fluid mechanics course in process engineering designed according to the students' wishes mixes lecture and exercise in co-teaching and flipped-classroom elements with gamification. The effectiveness increases as the number of points achieved in the exam increases by 31.9 % compared to the average of the four previous years. The withdrawal rate drops from 54.8 % to 17.4 % and the failure rate from 38.7 % to 23.7 %, which enhances efficiency. The students' self-report shows a better preparation to the course sessions, but they do not feel stressed much additionally. About 80 % of the initially attending students participate at the end of the course.

Keywords: Co-teaching, Flipped-classroom, Fluid mechanics, Gamification, Hybrid teaching

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1 Introduction

Economy and society are undergoing a profound transformation due to digitalization and the green transition of the economy. Due to the additional demographic change, more engineers are needed than are foreseeably available [1]. Oddly enough, about 35 % of bachelor's students drop out of their engineering studies [2]. Therefore, it can be seen as a social imperative of university teaching that all students achieve a degree by receiving the best education.

University teaching often took place exclusively in presence form at face-to-face universities, with a pandemic-related shift to more online or hybrid teaching, as students were unable to enter the lecture halls. However, an access restriction was already in place for parts of the students before and also after the pandemic, which is why a complete return to face-to-face teaching would represent a significant deterioration against these groups of people. Groups of people who are at least partially unable to participate in presence forms include students with children (approx. 8.5 % according to the Health Report for Students [3]) or other people in need of care in the household, with impairments, work outside of study (12 %) or also diseased students. Thus, the average of days of work incapacity of adults in 2022 in the age cohorts between 20 and 30 years is between 12 and 17 days [4].

Courses are also cancelled without substitution related to illness of the teachers or are held by less well-prepared and less suitable people as substitutes. For these reasons learning gains can fall short of expectations. The transformation to purely online or hybrid teaching offers possible solutions. But in the current semester 2022/2023, 75 % of the students state that the courses are held predominantly or exclusively in presence form [3]. This can be due to the requirements of the universities, the reluctance of the teachers, the fear of making teaching and thus one's own job partially superfluous or doubts about the quality of online teaching. The relevant criteria for the assessment of teaching-learning activities according to [5] are:

A) Effectiveness: how well are the learning outcomes obtained
B) Efficiency: effectiveness per time/cost of institution
C) Appeal: extent to which learners enjoy the teaching-learning activity

One could argue that all three items are different for students and teachers and that all have to be taken into account. Teaching works better if the teacher enjoys it and the efficiency for the students is also noteworthy. Furthermore, even if the teacher wants all students to achieve the learning outcomes, some of them are more interested in achieving a good grade.

1.1 Influence Factors on Learning

The Hattie study [6] is probably the best known and most comprehensive meta-meta study in the field of teaching and

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Table 1. Rules of thumb for absolute value of the effect size d [8] with the hinge point of Hattie.

$\|d\|$	0.01	0.20	0.40	0.50	0.80	1.20	2.00
Effect size	Very small	Small	Hinge point	Medium	Large	Very large	Huge

learning. In further studies, the effect sizes d are listed for currently 357 factors influencing learning [7]. Tab. 1 gives rules of thumb for the effect sizes. Negative effect sizes indicate a negative effect. Hattie determines the hinge point, i.e., the influence at which the implementation of a method is worthwhile, as 0.4. Implementations possible with little effort should also be considered with a smaller effect size.

According to the Hattie study [7], the lecture, as the usual form of teaching at universities, has an even more negative influence on learning with $d = -0.35$ than corporal punishment at home ($d = -0.33$). This may explain a greater loss of audience members in lectures than in tutorials and the often-small return rates of the final course evaluations.

The meta-meta study includes other negative influences like procrastination ($d = -0.41$), illness ($d = -0.51$), boredom ($d = -0.46$), and anxiety ($d = -0.38$). Positive influences have the use of gaming ($d = 0.41$), with the effect size of the individual meta studies for gaming varying from $d = -0.01$ [9] to 1.70 [10], flipped classroom ($d = 0.56$), feedback from tests ($d = 0.41$), outcome-based education ($d = 0.91$), co-teaching ($d = 0.21$), online-teaching ($d = 0.25$), and peer tutoring on tutor ($d = 0.43$) and on tutee ($d = 0.49$) interestingly better than the usually performed tutoring ($d = 0.37$).

1.2 Gamification

Gaming comprises two methods [11]. With game-based learning, the intention is to design the teaching-learning activity in a game. Gamification transfers game elements to a non-game environment such as the lecture hall. These game elements are mostly points, badges, levels [11], rewards, progress, story [12] etc., which can be obtained with assessable activities such as quizzes. Bedwell et al. [13] created a taxonomy for attribute categories of game elements. Landers [14] defines gamification of learning as „the use of game elements, including action language, assessment, conflict/challenge, control, environment, game fiction, human interaction, immersion, and rules/goals, to facilitate learning and related outcomes.“ While in serious games all attributes of games are implemented, only suitable elements for a certain issue are implemented in gamification.

The game elements are intended to:
- increase motivation and interest,
- increase participation,
- activate teachers and learners,
- arouse curiosity,
- facilitate focus and concentration.

The increase in motivation is derived from the self-determination theory for intrinsic motivation [15], where the psychological needs of experiencing competence (through the game principles), autonomy (free design of avatars, profiles, activities), and social belonging (leaderboard, awards, unlocking of goods) are satisfied [16]. During the pandemic, Inangil et al. [17] used gamification in nursing in online distance learning and were able to increase the motivation and knowledge of Generation Z learners. According to [14], the benefits of gamification for different subject contents and game elements are to be examined.

1.3 Teaching Fluid Mechanics

The teaching of fluid mechanics (FM) is traditionally divided into a theory-based lecture and an application-based exercise. The subject content can be subdivided into various basic topics, which are dealt with one after the other and then brought together at the end of the course, e.g., Bernoulli theory, Newtonian stress, and surface tension in the integral momentum theorem. Students often find the first topics disjointed and only attend the exercise, as it is considered more relevant for exams. Even the use of simulation software is considered to be an improvement, although this usually requires considerable additional effort from students [18], as they lack the necessary skills. For this reason, this is replaced by VR labs [19, 20] and used in tutorials [21]. The inclusion of blended learning through mixed classroom elements with online teaching and on-site sessions as a discussion venue has increased satisfaction by 18 % [22]. Gamification has also been used in FM and increased learners' intrinsic and extrinsic motivation [23]. Anonymous gamification was tested in a graduate FM course using Kahoot! but there was only an evaluation of the perception of effectiveness. The students preferred long form quizzes instead of short form, as they are more suitable in testing for the depth of knowledge [24].

1.4 Research Questions

Redesigning the course with a focus on gamification addresses the problems described before. The research questions are:

RQ1: what influence does the redesign have on effectiveness?
RQ2: what influence does the redesign have on efficiency?
RQ3: what influence does the redesign have on appeal?

2 Material and Methods

2.1 Student Sample

The investigations concern the course FM2 in the summer semester 2023 at TU Dortmund University in the Faculty of

Bio- and Chemical Engineering. The course is taught in the fourth semester of the bachelor's degree program in chemical engineering. The chemical engineers had the course FM1 in the winter semester 2022/2023 together with bioengineers. Informed consent forms are available from the participants. Of the 67 students identified by name, 41 are male, 15 are female, and 11 are without information regarding gender. The subject contents are similarity mechanics (Buckingham Π-theorem and scaling), Navier-Stokes equation, boundary layer theory, and turbulence with turbulence modeling. The course consists of 1 academic hour of lecture, 1 hour of tutorial and is accompanied by 2 hours of tutorials. There are six groups with two tutors each. After the semester, laboratory experiments on similarity mechanics take place on a wind tunnel.

2.2 Redesigned Course

The course is based on constructive alignment, an instructional framework for the holistic planning of courses of intended learning outcomes (ILO), teaching-learning activities (TLA), and learning outcome monitoring (LOM). The course is conducted hybrid (always online and on-site). Gamification is used to reduce procrastination and promote learning. In addition, this serves as the LOM of the constructive alignment in the single ILOs and TLAs. Flipped classroom elements are added to allow students to learn at their own pace and reduce the amount of disconnection. Since addressing students' problems is different in each semester, addressing the subject matter at the higher taxonomy levels of deep learning of the SOLO taxonomy [25] can hardly be done in 90-minute blocks. For this reason, the separation of lecture and exercise is canceled. Integrated laboratory experiments in virtual reality also serve as materials [19, 20, 26].

2.2.1 Co-teaching

The presence of the students may be an indicator of voting with their feet. As a result, many students do not seem to attend the lecture part of the course over the duration of the semester. The proportion of students in the exercise and tutorials also decreases, but this reduction is observed to a much lesser extent. The reasons for this may be a perceived lack of effectiveness, efficiency, or appeal, which can result, e.g., from a lack of optimal constructive alignment, and the benefit of the lecture for solving the practice-related problems of the exercise is then missed. However, this makes it very difficult for students to catch up on their skills and reach even higher taxonomy levels during exam preparation. The first step was to combine lectures and exercises so that one session of 90 min each takes place every week. Theoretical fundamentals are examined directly in application examples or the need for further theoretical methods is derived from the application examples so that theory and application permeate each other. The lecturers of the combined lecture and exercise are always present on site.

2.2.2 Hybrid Sessions

To allow students who are unable to attend in person and potentially students with visual impairments to participate better in the sessions and TLAs, the sessions are always held hybrid. The analog blackboard lectures are held digitally and streamed live via the video conferencing tool Zoom. Both teachers are always present, with the teacher who is not currently active taking over the Moodle and Zoom organization and answering questions in the chat. Based on the students' wishes, the theory materials are made available in advance and serve as flipped classroom material. The students should look at and work through the materials before the course. In addition, a structured learning platform is available in Moodle.

2.2.3 Gamification

Gamification elements were introduced to encourage students to stay on the ball and not procrastinate as presented in Tab. 2. As the award students can collect a maximum of half the points needed to pass the exam. Points can be earned in two ways. Firstly, by participating in quizzes in the courses. The personalized and clear assessment is ensured via a non-anonymous feedback function of the TU Dortmund University Moodle system. Students receive single-choice, multi-choice or free-text questions at different taxonomy levels, ranging from knowledge and understanding (unistructural understanding) to analysis (relational understanding) and relating to theoretical understanding and use cases. Addressing higher taxonomy levels also prevents quick searches on the internet or the use of AI chatbots such as ChatGPT. All points that can be collected in total correspond to the maximum points that can be credited

Table 2. Realization of gaming attributes.

Gaming attributes	Realization
Action language	Smartphones or laptops as game controller
Assessment	Points and leaderboard
Conflict/challenge	Exam and leaderboard
Human interaction	Think pair share
Control, environment, game fiction, immersion	–
Rules/goals	Leaderboard, points for exam clearly defined

Table 3. Evaluation methods and addressed research question.

Code	RQ	Description	Method
M1	3	Session attendance	Number of students attending the session and questions
M2	1	Exam results	Quantitative results of bachelor course exam
M3	2	FM course evaluations	Quantitative 4-point Likert-scale based survey of FM2 in 2023 and 2021
M4	1–3	Own course evaluation	Quantitative 5-point Likert-scale based survey of FM2 in 2023

for the exam and a linear interpolation is used. The second option for gaining points is for students in the current semester to lead a tutorial themselves. This method may seem daring, but has already been successfully tested in the past with regard to effectiveness, efficiency, and appeal [21].

The blend of flipped classroom and gamification elements is aimed at a change in behavior and attitude: students should prepare themselves better and thus achieve an increased learning gain, as well as attend the courses continuously in order to be able to learn actively.

2.3 Evaluation Method

The evaluation is carried out using quantitative methods. The coding, the research questions addressed, the description, and the evaluation method are given in Tab. 3.

3 Results

3.1 M1 – Session Attendance

The number of students attending the course is plotted in Fig. 1 for the sessions of FM2 in summer term 2023. Here, we count the number of people responding to the quizzes. In comparison to the counted number of students attending online and on-site, it demonstrates that all students take part at the quizzes. This corresponds to the active participation in the course. Fig. 1 presents responses given in the semester with gamification (continuous green line) in comparison with data from the FM1 course in 2019/2020, in which an audience response system was used (dashed black line). Normalization is based on the maximum number (2023 $N = 67$; 2019/2020 $N = 92$) of submitted responses. While the active participation rate does not fall below 80 % with gamification, it drops to 30 % in the comparison case. The decrease is also due to the perceptibly fewer students attending the sessions in the course of 2019/2020.

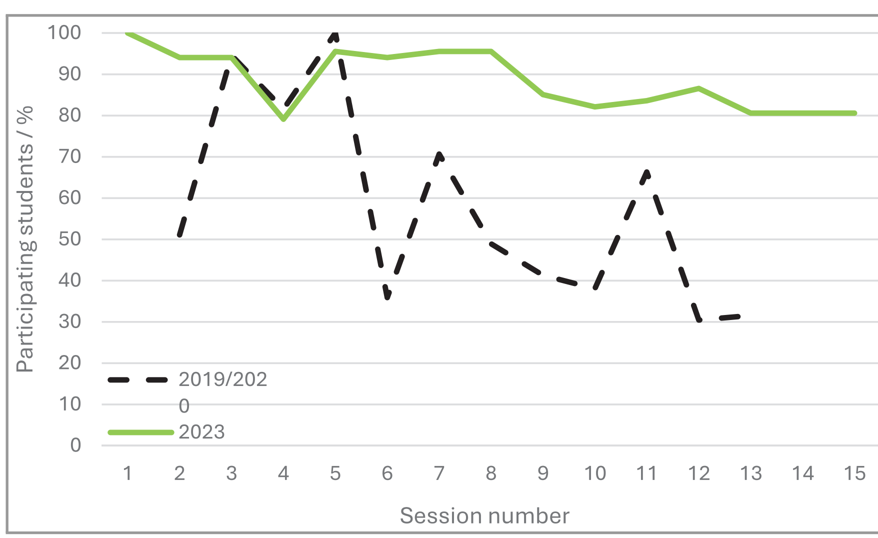

Figure 1. Number of actively participating students attending at the sessions in years with gamification (green, $N = 67$) and without gamification (black dashed line, $N = 92$).

3.2 M2 – Exam Results

Tab. 4 summarizes the results of the exams with the number of registrations and the actual number of exam participants, the failure rate in percent, the average score (80 total points in FM2 and 240 in FM12), and standard deviation. The exam in 2023 took place with gamification, whereby the FM2 part of the exam and the complete exam (FM12) are shown here. The points achieved through gamification are not included in order to ensure comparability. The comparison is made with the average of the years 2018–2021, as a different professor taught the course as a substitute in 2022. The number of students who did not pass the exam falls from 38.7 % to 23.7 %. Extra points gained from gamification are not taken into account and reduce the fail rate further. Another striking difference is the number of students who postpone the exam: 55 % of students in the comparison years postpone the exam, compared to 17 % in the gamification year. The effect size for the exam FM2 is in the range of very large and huge. The effect size d for FM12 is also large.

3.3 M3 – Course Evaluation FM 2021 and 2023

Tab. 5 gives the results of three specific questions about the workload and the ability for the students to follow. Although the absolute number of students was comparable, the

Table 4. Exam results of FM2 and combines exam FM12.

Exam		Registrations	Participants	Fails [%]	Mean value	Standard deviation	Cohen's d
FM2	2018–2021				17.7	18.4	
	2023 total		*38*		***43.9***	***17.0***	***1.48***
FM12	2018–2021	462	209	38.7	90.7	33.0	
	2023 total	*46*	*38*	*23.7*	*119.6*	*43.9*	*1.16*

Table 5. Results of specific items for FM2 in 2021 ($N = 6$) and 2023 ($N = 51$).

Item	2021	2023
I found the level of academic demand of the course for my study phase as appropriate	2.00	1.82
I found the pace of learning to be appropriate	2.00	1.86
I found my workload for this course appropriate	2.17	2.00

number of evaluations in 2023 is significantly greater, probably due to many students not doing the evaluation of the course.

3.4 M4 – FM Evaluation Summer Term 2023

Tab. 6 presents the results of the 5-point Likert scale survey regarding gamification. The answers are linearly quantified with +2 (yes), +1 (more likely yes), 0 (neutral), −1 (more likely no), and −2 (no). The students appreciate gamification and do not really feel stressed, rate session on-site to be better than online and would like to see gamification also in other courses.

Table 6. Mean values of evaluation.

RQ	Item	Mean
1	I learnt more with gamification than without gamification	1.65
1	I prepared much more due to gamification than for other courses	0.38
2	I rate my knowledge gain from the quizzes and answering them in relation to the time required as very good	1.43
3	The quizzes and answering even the wrong questions made me feel taken seriously	1.80
3	I would also like to have gamification in other courses	1.54
3	The quizzes caused me additional stress	−0.51
4	I think the sessions are better on-site than online	1.37
4	Gamification is better online than on-site	−0.86

4 Discussion

4.1 Effectiveness

The exam results (M2) show a clear increase in the points achieved compared to the average of several previous exams. Cohen's effect size for the examined part FM2 is very large with $d = 1.48$. The effect size for the overall exam FM12 with part FM1, in which gamification was used for testing and preparation purposes, is also clearly smaller at $d = 1.16$, but still very large.

In comparison with the effect sizes from the literature with lecture ($d = -0.35$), procrastination ($d = -0.41$), gaming ($d = 0.41$), flipped classroom ($d = 0.56$), feedback from tests ($d = 0.41$), co-teaching ($d = 0.21$) and online teaching ($d = 0.25$), there is a positive overlap of the influencing variables.

The students' self-perception (M4) indicates a significant increase in learning as a result of gamification (1.65, Tab. 5). The behavioral changes desired by the moderation process can be partially achieved, as some students prepare better for the course due to gamification (0.38).

4.2 Efficiency

The time required for teaching staff when using flipped co-gamification is higher for the first run due to the topical creation of questions and the creation of a student-specific question system. Nevertheless, the implementation is technically easily possible with a learning control and management system (LCMS) system such as Moodle. The questions should be varied for subsequent runs. At least an additional 30 min per session are required to evaluate the questions and make the leaderboard. Time savings result from the reduced failure rate. Regarding to the failure rate, only 23.7 % have to repeat the exam with gamification, while 38.7 % have to do so without gamification. If the cohort consists of 100 students and a maximum of 3 attempts are possible, this results in a steady state of 130 respectively 160 students. The correction time for an exam is around 30 min, which means that the difference of 30 students results in a time saving of 15 h. For N students, there is a time difference between gamification and normal mode in the semester with 15 weeks and two sessions per week:

$$\Delta t = t_{\text{additional effort}} - t_{\text{saved}} = 0.5\ \text{h} \cdot 15 \cdot 2 - 0.5\ \text{h} \cdot \frac{130}{160} \cdot N \tag{1}$$

Here, the break-even point for the time required is reached at 36 students. As the increase in the amount of learning is also significantly greater, this results in a clearly improved efficiency. It should also be considered that on average around 20 min per course are spent on questions and answering them, which means that the course is less crowded and much less strenuous for the teaching staff and that quantitative contexts that are not understood can be addressed directly.

The students' perception also shows a positive efficiency with 1.43 (M4, Tab. 6) and comparable results in 2021 and 2023 for workload, level of demands, and speed (M3, Tab. 5). The results in 2023 are slightly better.

4.3 Appeal

Participation in the events can be seen as voting with one's feet and thus as an expression of appeal (M1). The entire course is therefore attractive for the students, as participation hardly drops and remains at around 80 %. With 51 out of 67 (76 %) possible returns, the course evaluation can also be regarded as extremely high as return rates of around 10 % are typical at the university. The student survey also provides an indication of the cause: the special consideration given to incorrect thoughts and answers in the quizzes leads to learning by failure. These incorrect answers are also appreciated (1.84 as mean). A large proportion would also like to see gamification in other events (1.54). The fear that the additional surveys would cause stress did not materialize (−0.51).

4.4 Limitation

The comparatively very good exam results could be explained by an extremely high-performing cohort or a particularly easy exam. Further cohorts need to be examined for this.

5 Conclusion

In engineering, many courses are still held in a rigid corset of lecture and exercise, supplemented by tutorials and subsequent laboratory experiments. This case study combines various teaching methods and appears to be particularly suitable for difficult modules with high failure rates.

Theoretical and application-related parts are carried out jointly. The inclusion of gamification elements activates the students, while flipped classroom elements allow them to prepare themselves autonomously. The resulting experience of competence and the social integration of the leaderboard increases motivation and also makes the course more attractive. The exam results are greatly improved. As significantly fewer students withdraw from the exam, the negative influence of procrastination and the associated disorganized study plans is counteracted. As more students pass the exam at the first attempt, the effectiveness is also increased, thus reducing the time required by teachers. This approach combines various teaching methods and appears to be particularly suitable for difficult modules with high failure rates.

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Symbols used

d	effect size
N	number
t	time

Abbreviations

FM1	basics of Fluid Mechanics 1
FM2	basics of Fluid Mechanics 2
FM12	basics of Fluid Mechanics 1 and 2
ILO	intended learning outcome
LCMS	learning control and management system
LOM	learning outcome monitoring
M	method
RQ	research question
SOLO	structure of observed learning outcome
TLA	teaching-learning activities

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