Flipped classroom in secondary school physics education

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Abstract. This quasi-experimental pre/post-study with control group examines the effect of the flipped classroom method applied to basic physics courses at two German secondary schools (N = 150) in a three-month treatment. The focus of the study is the performance in a content knowledge test and the related non-cognitive attitudes as interest in the subject physics, motivation to do physics and the physics related self-concept. First results indicate that flipped classroom has a positive effect on the learning gain as well as on motivation and self-concept. Further analysis will look into parameters that moderate the effect of flipped classroom.

1. Theoretical background
Flipped classroom inverts traditional teaching methods by delivering direct instruction in online videos to be watched at home while typical homework activity is moved into the classroom. Introduced by Bergmann and Sams [1], the key concept of flipped classroom is to free up class time for activities that allow deeper exploration of the content. Out of class, students watch pre-recorded videos and screencasts at their own pace and familiarize themselves with a new topic. In class, an active learning setting enables them to apply and consolidate their knowledge. By outsourcing lectures, the role of the teacher shifts from instructing to coaching the students. There has been a lot of research on general aspects of flipped classroom [2–4]. Most studies refer to the US education sector, followed by a few other countries such as Australia, England, Taiwan, Singapore and Turkey.

The results of the studies regarding the effect of flipped classroom are divergent yet generally positive. Martin et al [5], Zheng et al [6] and Bell [7] found no evidence that students of Flipped classroom outperform students who were taught traditionally in a performance test. In addition, Lape et al [8] could not confirm improved student learning because of the inverted format. In this study, students of flipped classroom felt even less enthusiastic and prepared. By contrast, many studies report significantly better results in performance and self-evaluation tests [9–20].

Cognitive performance outcome is not the only aspect leading to a teaching method. Other aspects like the development of knowledge-gaining competences, communication, and personal and self-competences are also important. The beliefs and attitudes that influence the development of cognitive and non-cognitive competences are motivation, interest and academic self-concept [21–23]. According to research, flipped classroom provides a framework in which these attitudes can improve [13, 18, 24].

Studies on flipped classroom in the German education system have been targeted at the graduate and university level primarily [25–32]. The need for changing traditional learning settings to activate students seems to be greatest here. Even though the pedagogical framework in Germany has begun to shift from a teacher-centered toward a student-centered approach in the 1970s, reality shows that
lecturing and instructing are still prevailing teacher activities at German schools [33]. Particularly, in the ‘Oberstufe’ (11th to 12th grade with students aged 17–18) in which students prepare themselves for final secondary school examinations, the increased amount of content and only little time for consolidating the material tempts teachers to lecture most of the time. Hence, flipped classroom has been arousing interest in secondary school education as a method to activate and engage the students. Whereas math, grammar or history are subjects in which the application of flipped classroom begins to spread, the method seems to be only sparsely employed in physics education and has not yet been scrutinized by the research of physics teaching and learning.

2. Research questions
The diversity of studies and results does not make it easy to judge the efficacy of flipped classroom. Apparently, the educational context and the way in which the method is applied play a role. This study was conducted at two secondary schools in Germany and hence limits the results to this national frame of reference. The goal is to examine the effects of flipped classroom when applied to a general physics course in secondary classes in Germany. The questions of interest are:

1. How does flipped classroom influence the students’ performance in a content knowledge test, their motivation and interest in physics, and their physics related self-concept in comparison to traditional teaching format?
2. How do parameters (e.g. physics aptitude, achievement motivation, gender, homework discipline, digital competence) of the students moderate the effect of flipped classroom on the variables mentioned above?

3. Design and research methods
The quasi-experimental intervention study with control group comprised a sample of 150 students. Students in the federal state of Bavaria cannot chose between higher or lower science courses so there is no differentiation in the 11th grade. Physics students can enroll only in a general physics course in 11th grade in which a flipped classroom was tested for this study. The control group consisted of 80 students in four physics courses at two schools, involving four teachers in spring 2016. All teachers had several years of teaching experience and had taught this course at least three times before. The treatment group comprised 70 students; it was split in four courses at the same two schools. The identical teachers (except one change of person) taught the treatment group a year later in spring 2017. The treatment had a length of eight school weeks (24 lessons). Because of two spring breaks, the treatment lasted for three months. The novelty effect that generally improves motivation and performance initially when using technology based new teaching methods is likely to fade away in such a long treatment [34]. The control group had the same amount of time and breaks as the year before. The content covered in all courses was electromagnetic induction and the LC circuit. In almost every lesson the teachers carried out experiments in front of the classes. The learning videos for the students of the treatment group contained the same experiments that the students of the control group could watch during the lessons.

Because the term ‘flipped classroom’ designates any method that inverts in-class and out-of-class activities, it is necessary to describe the specific form in which this study applied a flipped classroom. By reviewing the literature, a common denominator can be distinguished which serves as a basic model of flipped classrooms [35–41]. Relying on it for this study, the teachers produced instructional online videos of five to eight minutes length and made them available online. They covered the entire content of the unit and showed recorded demonstrations of experiments, commented screencasts, and overview slides. The students were to watch the videos before class. At the beginning of each school lesson, a ten-minute interactive clicker quiz with four concept questions served to assess the level of knowledge and facilitated student-student interaction in a peer education setting [42]. Following the quiz, the students were given both mandatory and elective assignments with increasing level of difficulty to work on in pairs or groups. The students controlled their solutions in their own responsibility with sample solutions laid out. The role of the teachers was to provide an environment of active learning, to engage with students, to answer individual questions, and to give assistance in accordance to the students’ needs.
Essential problems were frequently solved together on the board. By contrast, the conventional way of teaching the control group involved live experiments conducted by the teachers, plenary conversations in an inquiry-based learning setting, providing results on the board, and short problem-solving assignments in class. The students had to solve most of the assignments at home. At the beginning of the next lesson, the teacher and the students discussed the solutions of the homework. The teachers taught all courses of both the control and the treatment group synchronously and in close cooperation.

To assess the performance gain of each student, a content knowledge pre/post-test was used whereas the student related parameters were collected by a pre/post-questionnaire. Both the test and the questionnaire were pseudonymized. The content knowledge test was a sample of modified problems from textbooks and previous A-level exams with different levels of difficulties and had been reviewed by a board of experienced physics teachers and researchers of physics education. Since it should resemble a typical written exam to display the students gain within the conventional framework of German secondary school education, there were almost no multiple-choice questions but open-response, problem-based assignments that were assessed by a highly structured solution manual. The reliability of the content knowledge test (post) reaches Cronbach’s $\alpha = 0.718$ which is acceptable in most educational research. The test score highly correlates with theoretically similar parameters and shows convergent validity (table 1).

| Variable                              | Pearson’s $r$ | significance |
|---------------------------------------|---------------|--------------|
| Last physics grade                    | .751**        | $p < .001$   |
| Motivation to engage in physics (post) | .445**        | $p < .001$   |
| Interest in physics as a school subject (post) | .516** | $p < .001$   |
| Self-concept in physics (post)        | .551**        | $p < .001$   |
| Self-concept induction and LC-circuit (post) | .591** | $p < .001$   |
| Last math grade                       | .596**        | $p < .001$   |

Low correlations with theoretically unrelated parameters like the sex ($r = .027, p = .744$), school enrollment ($r = .048, p = .563$), interest in subject German ($r = -.119, p = .149$) or Biology ($r = .020, p = .881$) give evidence of discriminant validity. The Likert-scaled items of the questionnaire largely stem from the PISA Test 2015 [43] which ensures high validity for the scales relevant to the study.

In this study, the learning gain for each student was measured by the normalized or Hake gain $g$, defined as the actual gain divided by the maximum gain possible [44]:

$$g = \frac{\text{post score} - \text{pre score}}{\text{max score} - \text{pre score}}$$

(1)

Originally introduced to compare FCI results of courses with traditional vs. interactive-engaging methods, normalized gain has become widely used in other contexts as well [45–48]. Whereas the difference $\Delta$ between post score and pre score measures absolute gains on any section of the score scale as equal, the normalized gain $g$ gives more weight to a gain in a higher section of the scale than to one in a lower section. Concretely, a student with a high pre-test score will have a higher $g$-value than a student with a low pre-test score even if both raise their scores by the same amount. It is more difficult to have a gain at the high section of the score scale than at the low end. That is why school grades are not linear to exam scores. Reinforcing the usage of $g$ in this study, the last physics grades of the students of the control group correlates higher with $g$ than with $\Delta$ ($r = .685**, p < .001$ vs. $r = .569**, p < .001$). This implies that $g$ better represents the physics aptitude of a control group student in addition to the last physics grade than $\Delta$. Consequently, normalized gain $g$ is the more suitable measure for the learning gain of students in this pre/post-study.
4. First results
The analysis of the data is still in progress and only the first results can be presented here. An ANOVA shows significant differences between control and treatment group. As shown in figure 1, there is a difference of learning gain between the groups, the average normalized gain of the flipped classroom students ($M = .461 \pm .024$) is significant higher that of the conventional classroom students ($M = .368 \pm .020$) with $F(1147) = 9.801, p = .002, \eta^2_p = .063$, which is a medium-sized effect.

![Figure 1. Average normalized gain.](image1)

When looking at the motivation to engage in physics (figure 2), the students of the control group experienced a significant loss of motivation during the 3-month-unit from $M = 1.688 \pm .077$ to $M = 1.506 \pm .087$ with $t(80) = 3.817, p < .001$. By contrast, the level of motivation of the students of the treatment group stayed the same. When comparing the development of motivation of both groups, there is a significant contrast between the average differences between post- and pre-value with $F(1148) = 6.413, p = .012, \eta^2_p = .042$, which shows a small-sized effect.

![Figure 2. Motivation to engage in physics](image2)

In the beginning, the interest in physics as a school subject (figure 3) was significantly higher in the treatment group than in the control group. There are no factors analyzed in the study that can explain this difference. Both the control and treatment group were taught by the same teachers hence this difference is regarded as random. It can be noted that the interest declined the same as the motivation in the control group whereas the treatment group did not lose interest during the unit. The drop of interest...
in the control group is significant, \( t(79) = 2.963, p = .004 \). However, the difference of interest development between both groups is statistically not significant \( F(1,148) = 1.282, p = .259 \).

![Figure 3. Interest in physics as a school subject](image)

The last parameter is the development of the physics related self-concept of the students. Figure 4 shows that the self-concept in the treatment group increases during the unit whereas the self-concept in the control group slightly declines. The effect is significant and small-sized, \( F(1148) = 4.565, p = .034 \), \( \eta_p^2 = .030 \).

![Figure 4. Self-concept physics.](image)

5. Discussion and outlook
Summarizing the main results up to this point, flipped classroom applied to physics courses at two German secondary schools showed positive effects. The students in the flipped classroom outperformed their colleagues in the conventional courses in a content knowledge test. Whereas in the short period of three months, interest and motivation decreased significantly in the conventionally taught courses, the value of both variables stayed the same in the flipped courses. Flipped classroom offers a setting in which the cognitive performance as well as related non-cognitive attitudes can develop better than in traditional classroom settings. It uses the classroom time more efficiently and facilitates a deeper learning with more student engagement.

Further analysis will investigate other main effects and moderator effects on the cognitive and non-cognitive output variables (research question 2). Also, group comparisons will help to identify possible teacher effects.
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