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Flipped classroom strategies and innovative teaching approaches in physics education: A systematic review

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Abstract
More and more educators are adopting the flipped classroom approach (FC) in their teaching, which entails using video-based learning outside of the classroom and interactive group learning activities inside. The aim of this review is to offer a summary of research on the use of flipped classrooms in physics education. A comprehensive analysis of 30 journal publications focusing on flipped classrooms in physics education was conducted. The analysis delved into flipped learning activities and psychological constructs utilized in these studies. Results indicate that compared to traditional classroom approaches, implementing FC in physics education has a positive impact on student outcomes.

Keywords: flipped classroom, physics education, learning activities

INTRODUCTION

Since the early 2000s, the teaching approach of flipped learning or inverted classroom has gained popularity. In the flipped classroom approach (FC), students study instructional material before class, which means that traditional classroom activities, such as lectures and content presentation, are moved outside the classroom and assigned as homework. During class students apply their learning through activities typically done as homework, such as problem-solving tasks, group discussions, and project work (Lo & Hew, 2017; Sohrabi & Iraj, 2016). FC model aims to provide students with more time and opportunities for active learning, collaboration, and problem-solving guided by a teacher (Flores et al., 2016). By moving lectures and content delivery outside the classroom, teachers can use classroom time to engage students in more interactive and hands-on activities that help students apply what they have learned and deepen their understanding of the subject matter (Prasetyo et al., 2018). School closures due to the COVID-19 pandemic raised teacher awareness of the value of campus class time and, at the same time, that many instructional formats can be done outside class. Moreover, developments in educational technologies and the Internet during the last two decades have led to the improved effectiveness of FC approaches. Yet most literature reviews and meta-analyses have been done some years ago (e.g., Cheng et al., 2018; Hew & Lo, 2018; van Alten et al., 2019) and show ambiguous findings with respect to teaching and learning activities as well as their effects. Physics education requires hands-on work, such as carrying out experiments and problem-solving tasks, but lose class time to lectures and other forms of instruction. The aim of this literature review is to contribute to insights into teaching and learning activities, media and platforms used and effects of FC approach physics education.

LITERATURE REVIEW

Flipped Classroom Approach

Although the term "FC" may be relatively new, the underlying concept has been around for many years, and many educators have been experimenting with variations of this approach for a long time (Sohrabi & Iraj, 2016). The rise of digital technology and online learning has made it easier to implement FCs on a larger scale, but the basic principles of this approach have been used by teachers and professors for many years (McGrath et al., 2017).

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Contribution to the literature

- This review is a rigorous source for physics education researchers.
- This review well documents pre-class and in-class flipped learning activities.
- This review presents the effect of FC instruction on psychological constructs measured in physics educational research.

In an FC, students are expected to come to class prepared with a basic understanding of the material, usually through watching pre-recorded lectures (Mylott, 2016) or reading materials before the class (Beatty et al., 2019; Miller et al., 2018). Students review pre-class materials, such as videos or readings, before class (Liu, 2021). Class time is then used for interactive activities, such as problem-solving or group work, where students apply the concepts learned in the pre-class materials. During class, the teacher can then provide more individualized and targeted support to students, answer questions, facilitate discussions, and help students work through problems. Generally, this also means that in class teachers are mostly focused on guiding students that have troubles with the assignment or the subject in general, paying less attention to the high-achieving students (Bergmann & Samm, 2012). Therefore, FC can also be understood as a way to make teaching more inclusive. The origin of FC goes back to the just-in-time-teaching (JiTT) model. In fact, two popular teaching methods were developed by physics instructors: peer instruction developed by Mazur (1999), and JiTT developed by Novak et al. (1999). FC and JiTT are related but distinct teaching approaches. The main difference between FC and JiTT approaches is the timing of the pre-class activities. In FC, students review pre-class materials before class, while in JiTT, students complete pre-class assignments that apply the concepts they learned in previous classes or readings. In both approaches, class time is used for interactive activities that allow students to apply their knowledge, but in FC, the pre-class materials are the primary source of content, while in JiTT, the pre-class assignments build on previous content.

While FC model can be effective in promoting active learning and student engagement, it requires careful planning and implementation (Vaughan, 2014). Teachers need to develop effective pre-class materials, ensure that students have access to the necessary resources, and create engaging in-class activities that build on the pre-class learning. The primary challenges associated with implementing an FC approach include the significant workload for teachers in creating flipped learning materials, as well as potential disengagement among students during the out-of-class learning component (Lo & Hew, 2017). Disengagement of students with the out-of-class work might be caused by anxiety of some students to engage with technology that is used to access out-of-class work (Holmes et al., 2015) or the lack of proper working Internet (Londgren, 2021). To solve this issue, some schools facilitate students with extra time in the computer lab and after school to view digital materials (McCrea, 2014). Yet students might also develop resistance to out-of-class work based on other factors, such as the belief that the teacher is mainly responsible for student learning, not the students themselves (McLaughlin & Rhoney, 2015). Making explicit what is expected of the students can help overcome this resistance (Findlay-Thompson & Mombourquette, 2014). To overcome the issue of teacher workload, teachers can start with a single module, rather than flipping a complete course at once. In this way, they may get the benefits of flipping without committing the significant time and energy needed for a complete implementation (Hsieh, 2017). This allows teachers to get experience with the pedagogical model and identify potential areas of student difficulty (e.g., completing before-class tasks, access to resources, and technology use) before implementing a fully flipped course.

Previous studies suggest that students tend to have positive perceptions and engagement towards FC approaches. Furthermore, implementing this method can lead to several indirect educational benefits, such as enhancing students' technology skills, promoting greater self-reliance in learning, and influencing changes in learning habits such as reviewing online materials prior to examinations (Lo & Hew, 2017). Although a few narrative reviews have been carried to examine the effects of FC (e.g., Akcayir & Akcayir, 2018; Lo & Hew, 2017; Lundin et al., 2018), generalization of their conclusions on effects of FC need to be interpreted with caution. These reviews are mostly based on small samples of studies and studies reviewed often lacked a proper research design to examine effects. The meta-analyses of Chen et al. (2018), Cheng et al. (2018), Hew and Lo (2018), and Lo et al. (2017) found only small positive effects of FC on student achievements in various domains. A meta-analysis carried out by van Alten et al. (2019) also showed small effects of FC on student achievement, but the variety between studies was enormous. This triggered van Alten et al. (2019) to do additional moderator analyses as the variety in studies probably means that the effects are not the same for different contexts, domains and approaches. The findings from their moderator analyses, however, did not contribute much to deeper insights. Two main findings from the moderator analyses that nuanced the general small effect of FC on student achievement were class time and one particular teaching activity. When class time was reduced, FC had a smaller effect on student achievement but when quizzes were added to the teaching at the campus, FC had a larger effect on student achievement. The latter can be understood as a way of checking students' preparation for class as well. But no other moderator effects were found, and no effects were found on students' perceived learning outcomes and their satisfaction with teaching.

Flipped Learning in Physics Education

Although van Alten et al. (2019) reported no significant differences in effects of FC between subject domains (natural sciences vs. other domains), the nature of physics education with a lot of hands-on student work might be a reason that FC is working differently, compared to teaching in other subject matter domains. Amanah et al. (2021) reviewed 33 journal articles on physics learning and concluded that FC has positive effects on student achievements, although it is not clear how the authors came to this conclusion. They also presented a variety of teaching and learning activities in class such as class discussions, question-and-answer, experiments and demonstrations, quizzes and problem-solving tasks. Finally, they confirmed the challenges of teachers as described above with more time needed for preparing class and students having problems with pre-class activities leading to unprepared students in class. In a quasi-experimental study, not included in the literature review of Amanah et al. (2021), Finkenberg and Trefzger (2019) confirmed the conclusions from Amanah et al. (2021) about learning effects of FC. Students in an FC condition outperformed their peers in a regular teaching condition in learning physics and had a significant higher self-concept with respect to physics, compared to the other students. Both student groups were taught by the same teachers. Finally, in a study of Limueco and Prudente (2018), also not included in the sample of Amanah et al. (2021), students attending an FC approach were compared to students in a regular teaching condition. The authors showed that students in both conditions improved their understanding of physics (i.e., energy momentum conceptual survey), but that students in FC condition improved significantly more. Students evaluated FC approach positively emphasizing immediate feedback of their teacher in class.

This Study

As mentioned above, both the narrative reviews and meta-analyses were published before the COVID-19 pandemic, which means these do not address recent developments in attitudes towards FC and technologies that can be used for FC. Moreover, both types of reviews yield ambiguous findings with respect to effects of student achievement and satisfaction, which means more insight is needed regarding FC instruction. The only systematic review of FC in physics teaching was Amanah et al. (2021). However, this review was published in a conference proceeding covering 2016 to 2021 and used Google Scholar as the database for studies. Moreover, there are reviews (Dogan et al., 2021; Wright & Park, 2022) and meta-analysis (Turan, 2023) related to science and STEM education, but to our best knowledge there are no systematic literature reviews on the usage of FC in physics teaching. Our review, thus, was directed by the following research questions:

1. What flipped learning activities are used in physics teaching?
2. What is the effect of FC instruction on psychological constructs measured in physics educational research?
3. What is the trend of FC research on physics learning from 2000 to 2023?
4. What teaching methods are integrated with FC approaches?
5. Which online media and platforms are usually integrated with FC approach?

METHOD

In this section initially the search terms used, and inclusion criteria determined for this study are listed. Then, the coding form and the data extracted from the identified studies are presented. Finally, the study selection procedures are explained.

Search Terms and Inclusion Criteria

For this review three electronic databases were searched: SCOPUS, ERIC and WoS. The search string with relevant keywords and Boolean operators was, as follows for these three databases: ((‘flip’ or ‘invert’) AND (‘class’ or ‘learn’ or ‘strategy’ or ‘education’ or ‘model’ or ‘approach’)) AND (‘physics’)). The search was run between 18-20 November 2022.

The search was not limited to any specific time period; subsequently, however, after search and refinement processes the focus fell on the studies published between 2013 and 2022 (10 years). To be included in this systematic and rigorous review, the studies had to be closely related the usage of FC method in physics education, such as in teaching mechanics, electricity, magnetism and optics. The studies had to be research articles in peer reviewed academic journals because peer review is a necessary criterion for counting scientifically comprehensive studies. Conference preceding, dissertations, and book chapters were not included, but no restrictions were set for the language of instruction. Lastly, no constraints were imposed on the location of the studies, except that the documents had to be written in English.

Coding Form and Extracted Data

The following information were mined from each article: article title, author/s, year of publication, journal of publication, country, content area, school level, construct/s measured, study design, duration of the implementation of FC, participants, integration of FC with other teaching methods, learning media and platforms used for content learning, pre-class activities, in-class activities, after-class activities, and the effect of FC. The first two authors were separately extracted as data from the manuscripts. Any inconsistencies among the extracted data were revised, discussed and fixed by the authors prior to data analysis.

Study Selection

We employed a five-stage screening process (Balta et al., 2017) at the very beginning of the article mining from peer-reviewed journals. In the first stage, we identified a total of 1,579 records in the databases. While our search string allowed the flexibility to find a variety of terms used to refer to flipped teaching in physics, it also produced many unrelated search results. Due to repetition across the three databases we searched, many were excluded leaving 958 potentially relevant studies. In the second stage, after skimming the titles and abstracts, many articles were removed because they were not relevant to the purpose of our study, such as articles not related to FC or physics. Consequently, 261 studies were considered appropriate for full review in the third stage.

In the third stage, these 261 studies were evaluated based on our inclusion criteria, which left us with 42 eligible articles. The most common reason for excluding studies was that they did not involve FC instruction. At this stage, conference proceedings, book chapters, book reviews, web article, theses, dissertations and meta-analysis were also excluded.

In the fourth stage, the coding form was completed with the data reported in these studies. Fifteen of them were removed because they did not compare any aspects of student activities under FC approach. Ten studies did not have the mandatory data such as pre-class and in-class flipped activities (for example see Capone et al., 2017) or insufficient context was provided for FC intervention (for example see Wang et al., 2018), or studies focusing on the development of FC curricula/activities/technologies (for example see Wang et al., 2018). Finally, the reference lists of all the studies selected in the fifth stage were reviewed to identify additional studies. In this way, three further studies were identified, and the coding form was completed for 30 studies.

RESULTS

Characteristics of the Included Studies

Prior to answering the five research questions, we first provide an overview of the characteristics of the studies that are included in this review. Of the 30 included studies, eight (26.7%) were published by researchers from Turkey. Five (16.7%) studies were from the USA, 10 (33.3%) were from Asia-Pacific countries (Indonesia, Philippines, Taiwan, China, and Malaysia), five (16.7%) studies were from European countries (Spain, Greece, and UK), two (6.7%) studies were from Middle East (Saudi Arabia, and UAE), and one study was the collaboration of authors from the USA and South Korea.

All studies were conducted at the undergraduate (n=23) or secondary school (n=7) levels. A total of 3,846 students were subjected to FC in all studies we reviewed, which corresponds to 129 students on average per study. Putri and Purwaningsih's (2021) qualitative study assessed views of four students on the application of FCs in physics learning through interviews. On the other hand, Gómez-Tejedor et al's. (2020) experimental study lasted four years to locate the effect of FC on 1233 students' academic performance.

In the 30 FC interventions, various content areas of physics were involved. For example, at the undergraduate level, mechanics, electricity and magnetism were covered in Miller et al. (2016), and thermal physics by Hung and Young (2021). Similarly, at the secondary school level, for example, laws of motion were covered in Derbashi (2017), temperature was covered in Lo et al. (2018), centripetal force (Pierratos et al. 2022) and pressure and buoyant force were covered in Koray et al. (2018). Several studies did not report the content area in their research (for example Sengel, 2015).

The 30 articles included reviewed were collected from 22 different journals. Two articles per journal were published in nine journals while one article per journal was identified for rest of the 12 journals. Except for the Koray et al. (2018) and Putri and Purwaningsih's (2021) qualitative studies, the studies were quantitative. Among the 28 quantitative studies 12 were experimental, 11 were mixed method and five were survey design (for example Matthews & Dostal, 2020). The duration of FC implementation varied between eight hours and four years. Cagande and Jugar (2018) executed a FC approach over the course of eight sessions, where the class time for each session was approximately one hour. Similarly, Wood et al. (2016) implemented FC in eight sessions, where each lecture was approximately 50 min long. Gómez-Tejedor et al. (2020) carried out FC instruction for four years, the longest duration. Sengel (2016) investigated the effectiveness of FC instruction for two years while the majority of the reviewed studies implemented FC approaches for about eight weeks.

Figure 1. Pre- & in-class activities (Source: Authors' own elaboration)

Table 1. Constructs measured in 30 studies

	Effective	Neutral	Ineffective
Achievement	8	1	0
Anxiety	1	0	0
Attitude	4	0	0
Critical thinking	2	0	0
Engagement	3	0	0
Innovation skills	1	0	0
Learning	4	0	0
Motivation	4	1	0
Perceptions	4	3	0
Performance	4	1	0
Satisfaction	2	0	0
Self-confidence	1	0	0
Self-efficacy	0	1	0
Self-perceived competences	1	0	0
Self-regulation	0	1	0
Self-sufficiency	2	0	0
Understanding	5	0	1
View/opinion	4	0	0

Appendix A provides a summary of the key findings from the studies that were included. In the following sections, the headings are provided for each research question.

Flipped Classroom Activities Used in Physics Learning

Watching instructional videos as a common pre-class FC strategy. In the reviewed articles we identified several other learning activities that were commonly used along with watching videos. **Figure 1** indicates the pre-class and in-class activities used in FC.

Along with watching videos two more learning activities are significant in the pre-class phase. These are doing quizzes and reading learning materials assigned prior to face-to-face meetings. The online automatically-graded quizzes were implemented to ensure that students were watching the videos. For depth of learning, students were given chapter reading assignments in their textbooks.

On the other hand, problem-solving, discussion, group work, lecturing and doing experiments were main in-class activities (**Figure 1**). Only five articles reported after class activities. These were project assignments, lab reports, problem-solving, and home tasks.

Effect of Flipped Classroom Approach on Psychological Constructs Measured in Physics

To determine the effect of FC interventions researchers measured several psychological constructs: student achievement and motivation, self-sufficiency, understanding, attitudes, perceptions, satisfaction, learning, critical thinking, performance, interactions, self-regulation, self-efficacy, views, and innovation skills. Among these, achievement, attitude and perception were three most commonly measured constructs. In some studies, several constructs were measured together. For instance, Bawang and Prudente (2018) measured performance, attitude, engagement and understanding in their study. Measuring all the above

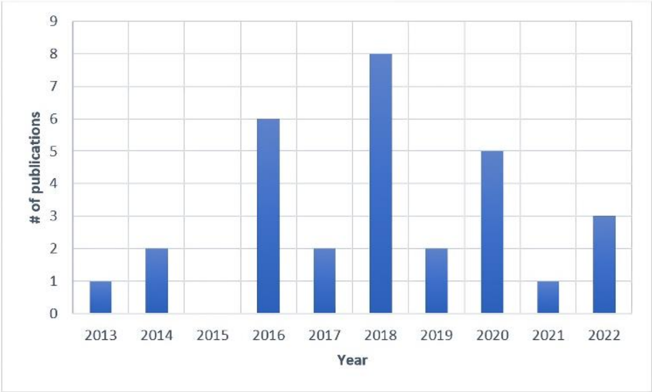

Figure 2. Studies on FC published by year (Source: Authors' own elaboration)

constructs were carried out with achievement tests, surveys, observations, interviews, home tasks, quizzes and lab reports.

Table 1 presents how many times each construct measured along with the effect (effective, neutral, and ineffective) of FC.

Student achievement after FC intervention was measured in nine studies and in eight of them (for example, Asiksoy, & Sorakin, 2018) the effects of the intervention were significant while in one of them (Robinson et al., 2020) it was not significant. Similarly, motivation was measured in five studies and the effect of FC was significant in four studies while insignificant in one study (Cagande & Jugar, 2018). Among all studies the effect of regular instruction was higher in only one study (Putri & Purwaningsih, 2021), where authors attempted to reveal students' understanding of physics concepts after FC employment. Moreover, the effect of FC was ineffective in eight studies. For instance, Sun et al. (2017) found no effect of FC on students' self-regulation.

Trends in Flipped Classroom Studies in Physics Education

The five-stage screening process yielded FC physics learning studies between 2013 and 2022. Based on the 30 articles identified, the highest number of physics teaching FC intervention studies occurred in 2018 (n=8), and the least in 2015 (n= 0).

As depicted in **Figure 2**, the number of articles published varied between years with an average number of three publications per year in 10-year time span.

Teaching Methods Integrated With Flipped Classroom Approach

Of the 30 studies we reviewed, 11 FC applications were integrated with supportive learning methods. In other words, 63.3% of the studies were pure FC interventions without the integration of other learning methods. Keller's ARCS model was used in two studies (Asiksoy & Ozdamli, 2016; Asiksoy, 2018), project-based learning was implemented along with FC in three studies (Limueco & Prudente, 2018; Miller et al., 2016; Torío, 2019). Other integrated teaching methods were creative problem solving (Rahayu, 2022), peer instruction (Wood et al., 2016), team-based learning (Miller et all., 2016), gamified environment (Ahmed & Asiksoy, 2021), problem-based learning (Eldy et al., 2019; Sengel, 2016), cooperative learning (Sengel, 2016), and 5E learning cycle (Asiksoy & Ozdamli, 2017).

Online Media and Platforms Integrated in Flipped Classroom Approach

To support pre-class activities using FC approaches, web-based learning media is required. These online learning platforms provide teachers with the tools they need to deliver content outside of the classroom and facilitate active learning in class. They can be used to upload and share content, assign readings and assessments, and facilitate class discussions. Many studies used the learning management system (LMS) such as Google Classroom (Rapi et al., 2022), Moodle (Ahmed & Asiksoy, 2021), and institutional platforms (Bawaneh & Moumene, 2020) designed specifically for online learning. Some studies used social media such as WhatsApp (Al-Derbashi, 2017), YouTube (Kettle, 2013), and Facebook (Limueco & Prudente, 2018), to support pre-class learning activities in FC. During the in-class activities other instructional technologies that support active learning such as clickers, simulations, course books, demonstrations, quizzes, and spread sheets were used.

DISCUSSION

This systematic literature review gives insights into the teaching and learning activities applied in FC in physics education. Pre-class activities mostly include watching videos, reading learning materials and taking quizzes, and in-class activities mostly include group work, class discussions and problem-solving tasks. With respect to the in-class activities, the findings are similar to Amanah et al. (2021), although relatively more studies were found with group work and problem-solving tasks during class. In contrast with the meta-analysis of van Alten et al. (2019), the findings of the current review study show no lectures in class with the exception of a small number of studies with micro-lectures in class. Moreover, the current review showed both the pre-class and in-class teaching and learning activities, providing a more comprehensive overview of teaching with FC approach compared to previous literature reviews.

With respect to learning effects, the findings of the present review indicate that physics students in FCs tend to achieve better learning outcomes, or at least perform similarly to those in regular classrooms. This conclusion is consistent with some earlier reviews of FC research conducted on FC (Amanah et al., 2021; Lo & Hew, 2017).

Similar effects have been found for the affective outcomes of students, which means that students in FC are more motivated for learning in physics, are more engaged with the topic, showed less anxiety for physics and have a more positive attitude towards physics compared to their peers that attended regular teaching. These effects on affective student outcomes are additional to previous work as both the meta-analysis of van Alten et al. (2019) and the quasi-experimental study of Finkenberg and Trefzger (2019) did not find significant effects on students' affective outcomes. Only one study in the current review focused on anxiety for physics as an outcome and found a positive effect with an FC approach. As physics is commonly understood as a difficult subject for some students, more emphasis on decreasing student anxiety might be a focus for future FC studies in physics education.

Finally, in most studies LMS that is used for schoolwork is used to support the pre-class learning activities of students. This is a similar outcome as found in the literature review of Aminah et al. (2021). The use of LMS makes the integration of FC approach with other teaching and learning activities in a course or module easier as both teachers and students are acquainted with LMS for their teaching and learning.

Limitations and Directions for Future Research

The current literature review is based on peer-reviewed research articles, which most commonly do not provide many details on how FC is used on teaching and learning. This means that the implications for teaching practice, based on a literature review like this one, are limited. A multiple case study might solve this issue with observations, log data and in-depth interviews with teachers and students to get a rich understanding of potential effective FC use in teaching and learning physics.

A second limitation is the number of studies found. Although our analysis of the 30 articles found gives an idea of both the teaching and learning activities and their effects in physics education, no firm conclusions can be made. A meta-analysis on FC specific on one or two student outcomes, with domain or school subject as moderator, can give more rigorous answers on whether FC approach in physics education shows some effects. A similar meta-analysis has been done by van Alten et al. (2019), but their literature search ended in May 2016. A follow-up study will give more recent insights into FC approach, especially from the literature that is published during and after the COVID-19 pandemic.

CONCLUDING REMARKS

This literature review on FC in physics learning provides insights into teaching and learning activities as part of FC approach as well as the effects of this approach for student learning and affective outcomes. Implementing an FC approach can also help teachers to make their teaching less-teacher centered and more student-centered as the preferences and needs of the students are more central in in-class teaching than in regular lecturing. Consequently, physics teaching can become a little more inclusive addressing the needs of students who show some anxiety to learning physics.

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APPENDIX A

Table A1. Summary of the key findings

Authors	Country	Journal	Construct measured	Study design	Duration	Content area	School level	Participants	Integrated with	Learning media & platforms
Ahmed and Asiksoy (2021)	Turkey	Sustainability	Self-efficacy perception innovation skills	Experimental	10 weeks	Ohm's law, resistances RC circuit, & Coulomb's law	University	70 students	Gamified environment	Moodle
Al-Derbashi (2017)	UAE	Journal of Education & Practice	Understanding attitudes	Experimental	3 weeks	Laws of motion	High school	59 students		WhatsApp
Asiksoy (2018)	Turkey	Quality & quantity	Achievement motivation self-sufficiency	Mixed method	8 weeks	Movement on earth & work-energy	University	66 students	Keller's ARCS	Moodle
Asiksoy and Ozdamli (2016)	Turkey	EURASIA Journal of Mathematics, Science & Technology Education	Achievement motivation self-sufficiency	Mixed method	8 weeks	Movement on earth & work-energy	University	66 students	ARCS model	Moodle
Asiksoy and Ozdamli (2017)	Turkey	Croatian Journal of Education	Achievement opinion	Mixed method	10 weeks	Mechanics	University	94 students	5E learning cycle	Moodle
Asiksoy and Sorakin (2018)	Turkey	International Online Journal of Education & Teaching	Achievement anxiety	Experimental	4 weeks		University	61 students	E-integration of clickers activities	Moodle
Bawaneh and Moumene (2020)	Saudi Arabia	EURASIA Journal of Mathematics Science and Technology Education	Motivation understanding	Experimental	2 months	Medical physics	University	123 students		Institutional platform, Facebook, WhatsApp
Bawang and Prudente (2018)	Philippines	Advanced Science Letter	Performance attitude engagement understanding	Mixed method	8 weeks	Mechanics	University	37 students		
Cagande and Jugar (2018)	Philippines	Issues in Educational Research	Motivation understanding	Mixed method	8 hours	Kinematics graphs	University	155 students		YouTube & PPT
Eldy et al. (2019)	Malaysia	Journal of Technology & Science Education	Achievement	Experimental	1 semester	On topics of classical mechanics.	High school	76 students	Problem-based learning	Padlet
Gómez-Tejedor et al. (2020)	Spain	Computers & Education	Academic performance	Experimental	4 years	Physics & electricity lab	University	1,233 students		Institutional platforms
Hung and Young (2021)	Taiwan	Australasian Journal of Educational Technology	Achievement	Mixed method	5 months	Thermal physics	University	11 students		
Kettle (2013)	UK	Physics Education	Learning achievement attitude	Mixed method	5 weeks	high school	12 students		Phet, YouTube, & Moodle	
Koray et al. (2018)	Turkey	Turkish Online Journal of Educational Technology	Views	Qualitative	5 weeks	Pressure & buoyant force	High school	10 students		
Limueco and Prudente (2018)	Philippines	Advanced Science Letters	Perception understanding	Mixed method	3 weeks	Momentum & impulse & work-energy	High school	99 students		Facebook
Lo et al. (2018)	China	Computers & Education	Achievement	Experimental	10 weeks	Definition & use of temperature	High school	244 students		

Table A1 (Continued). Summary of the key findings

Authors	Country	Journal	Construct measured	Study design	Duration	Content area	School level	Participants	Integrated with	Learning media & platforms
Matthews and Dostal (2020)	USA	The Physics Teacher	Satisfaction achievement	Survey	5 semesters	University calculus-based general physics	University	45 students		
Miller et al. (2018)	USA	Frontiers in Education	Performance	Experimental	2 semesters		University	153 students		Perusall
Miller et al. (2016)	USA & South Korea	Physical Review Physics Education Research	Engagement	Experimental	2 semesters	Mechanics, electricity, & magnetism	University	161 students	Project- & team-based learning	
Mylott et al. (2016)	USA	Journal of Science Education & Technology	Satisfaction perception attitudes	Survey	10 weeks	Waves & optics & lenses & refraction	University	67 students		Smart-physics framework & YouTube
Mzoughi (2014)	USA	Procedia-Social & Behavioral Sciences	Perception	Survey	1 semester	Introductory physics	University	65 students		
Pierratos et al. (2022)	Greece	Physics Education	Attitude	Survey	N/A	Centripetal force	High school	80 students		
Putri and Purwaningsih (2020)	Indonesia	Mexican Magazine of Physics E	Understanding attitudes	Qualitative	8 hours	Work-energy & impulse-momentum	High school	4 students		Google Classroom
Rahayu et al. (2022)	Indonesia	Journal of Indonesian Science Education	Creative thinking	Experimental	3 months		University	66 students	Creative problem-solving	
Rapi et al. (2022)	Indonesia	Journal of Indonesian Science Education	Understanding critical thinking	Experimental			University	31 students		Google Classroom
Robinson et al. (2020)	USA	Journal of Science Education & Technology	Perceptions performance	Survey	3 years	Fundamentals of physics	University	113 students		
Sengel (2014)	Turkey	Journal of the Balkan Tribological Association	Achievement approaches and attitudes	Experimental	6 weeks		University	78 students		
Sengel (2016)	Turkey	Computers in Human Behavior	Achievement perception engagement	Mixed method	2 years	Virtual physics laboratory course	University	137 students	Problem-based & cooperative learning	YouTube
Sun et al. (2016)	Taiwan	British Journal of Educational Technology	Self-regulation	Mixed method	1 semester		University	181		Open Course Ware
Torío (2019)	Germany	Journal of Technology & Science Education	Satisfaction achievement	Survey	4 months	Solar thermal systems	University	24 students	Project-based learning	Blogs
Wood et al. (2016)	UK	Physical Review Physics Education Research	Characterization of interactions	Experimental	8 hours	Newtonian mechanics thermos dynamics waves, optics, & crystals	University	200 students	Peer instruction	Institutional platform