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Research Article

Unlocking the Power of Flipped Learning: Revolutionizing Science Education

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Abstract

Flipped learning (FL) is an increasingly popular approach in SL that shows great promise for improving student learning outcomes and engagement. This review article explores the potential benefits and future research directions in FL in science learning (SL). Emerging trends in FL include the use of interactive video tools, mobile learning, and virtual and augmented reality technologies. Future research could investigate the effectiveness of these tools in enhancing SE and learning outcomes in SL, as well as their impact on student motivation and self-regulated learning (SRL). The article presents a comprehensive literature review that summarizes the previous research findings and highlights the effectiveness of FL in SL. However, implementing FL presents unique challenges, such as the need for access to technology and the time commitment required for both students and teachers. The article provides best practices for implementing FL in SL, which includes a focus on student-centered learning, interactive activities, and ongoing assessment. FL has the potential to revolutionize SL and improve student outcomes. It is a flexible and dynamic approach that can be adapted to different science disciplines and learning contexts. Therefore, the article emphasizes the need for further research in FL and the importance of its implementation in SL.

Keywords: *Flipped learning (FL), Science learning (SL), emerging trends, challenges, student engagement (SE)*

Introduction

In recent years, FL has gained increasing attention as an innovative approach to teaching and learning. It involves the inversion of the traditional classroom model, where students are exposed to content prior to class, usually in the form of videos or other multimedia resources, so that they can engage in more active and collaborative learning during class time. This approach has been applied across a variety of disciplines, including SLFL refers to a model of instruction in which students are exposed to content prior to class, usually in the form of videos or other multimedia resources, so that they can engage in more active and collaborative learning during class time[1]. This approach has been applied across a variety of disciplines, including SL.

SL is an area that has seen a significant shift towards FL in SL and the inversion of the traditional classroom model is supported by numerous studies. For example, Bergmann and Sams (2012) note that FL has become increasingly popular in SL, and describe the inverted classroom model as a key feature of this approach. Similarly, Mason *et al.* (2013) describe FL in SL as a pedagogical approach that involves the use of pre-class readings or videos, followed by in-class activities that focus on application and problem-solving [2].

Research has shown that FL can be an effective approach for improving student learning outcomes in SL. Studies have found that FL can lead to increased SE, improved critical thinking skills, and enhanced conceptual understanding. For example, Mason *et al.*

(2013), Deslauriers *et al.* (2011), and Lage *et al.* (2000) found that FL can improve SE, critical thinking skills, and conceptual understanding [2,3,4]. Moreover, the use of interactive video tools, such as EdPuzzle and PlayPosit, has also shown promise in promoting SE and understanding [5]. Another developing trend in FLis mobile learning, which allows students access to pre-class materials wherever they are and whenever they want by using smartphones and tablets [6]. Research has suggested that mobile learning can improve SE and learning outcomes in SL [7,8].

Virtual and augmented reality technologies have also gained interest in SL, providing students with immersive learning experiences that promote engagement and interactivity. Studies have shown that these technologies can enhance student learning outcomes in SL [9,10].

Flipped learning also has the potential to promote the development of important skills such as self-regulation and metacognition [11]. Research has suggested that FL can improve student motivation and self-regulated learning (SRL) in SL [1, 12], while FL has been studied extensively in biology and chemistry education, there is limited research on its effectiveness in other science disciplines, such as physics [13,14]. Future research could explore the effectiveness of FL in different science disciplines, and identify potential disciplinary differences in the effectiveness of this approach.

Finally, there is a need for research on the impact of FL on long-term student achievement and retention in SL [1], While many studies have investigated the impact of FL on student learning outcomes, there is limited research on its impact on long-term student achievement and retention in SL.

Therefore, FL is a promising approach for improving student learning outcomes and engagement in SL. Future research should explore emerging trends and technologies in FL, investigate the impact of FL on student motivation and SRL, explore the effectiveness of FL in different science disciplines, and investigate the impact of FL on long-term student achievement and retention in SL. Overall, FL has the potential to transform the way science is taught and learned, and future research should continue to explore and refine this instructional approach. However, implementing FL in SL presents unique challenges, such as the need for access to technology and the time commitment required for both teachers and students [15,16]. Nonetheless, the potential benefits of FL for improving student outcomes in SL are vast. Therefore, this review article aims to provide an overview of the current state of research on FL in SL, focusing on its effectiveness, challenges, and best practices. It also seeks to identify potential areas for future research, including emerging trends in FL, disciplinary differences in its effectiveness, and its impact on long-term student achievement and retention. In conclusion, FL has the potential to revolutionize science education, and future research should continue to explore and refine this promising instructional approach [17,18].

Objective of the study

The main objectives of this review article is to

I. explore the potential benefits and challenges of implementing FL in SL, including emerging trends and best practices,

II. evaluate the effectiveness of FL in enhancing SE, motivation, and learning outcomes., and

III. Identify future research directions for FL in SL.

Theoretical foundation of FL

FL is a popular pedagogical approach that has been widely adopted in SL due to its potential to enhance student engagement (SE) and learning outcomes. This approach is based on constructivist learning theories that emphasize the importance of active, student-centered learning. As such, students access instructional materials before class and use class time to engage in active learning activities, such as group discussions or problem-solving. This approach supports a constructivist learning approach by providing students with the opportunity to engage with the material at their own pace and in a way that is meaningful to them [19].

Active learning is another theoretical foundation of FL that involves engaging students in the learning process through hands-on activities. FL builds on the principles of active learning by providing students with the opportunity to engage with instructional materials before class and then using class time to engage in more in-depth, active learning activities[20].This approach is based on the idea that students learn best when they are actively engaged with the material.

Social cognitive learning theories also support the use of FL in SL. This approach emphasizes the importance of social interaction and modeling in the learning process. FL supports a social cognitive approach by providing students with the opportunity to engage with the material in a social context, such as through group discussions or collaborative problem-solving [21].Thus, the use of FL in SL aligns with social cognitive learning theories, which emphasize the value of social interaction and modeling in the learning process.

The use of multimedia resources, such as videos or interactive simulations, is also an important component of FL in SL. According to the cognitive theory of multimedia learning, which is based on the idea that people learn better when information is presented in both visual and auditory formats, the use of multimedia resources can enhance student learning outcomes [22,23]. This approach provides a variety of ways for students to interact with the material, which can support SE and understanding.

A further developing trend in FL for SL is mobile learning. Mobile learning is the process of accessing educational resources and participating in learning activities using portable electronic devices, such as smartphones or tablets. Mobile learning can improve SE and learning outcomes in SL, claims the ubiquitous learning theory, which highlights the value of anytime, everywhere learning [22,24]. Virtual and augmented reality technologies are also emerging trends in FL for SL. These technologies allow students to engage with the material in a more immersive and interactive way, which can enhance SE and understanding. According to the cognitive load theory, which is based on the idea that learners have a limited capacity for processing information, the use of virtual and augmented reality technologies can reduce cognitive load and enhance student learning outcomes [24].

In conclusion, the theoretical foundations of FL in SL are rooted in constructivist learning theories, active learning, social cognitive learning theories, and the cognitive theory of multimedia learning. Emerging trends in FL include the use of multimedia resources, mobile learning, and virtual and augmented reality technologies. Future research in FL for SL should continue to explore these trends and evaluate their effectiveness.

Methods and Methodology

This study was conducted using a systematic search of electronic databases, including Google Scholar, Web of Science, and ERIC. The search was conducted using specific search terms related to FL in SL, such as "FL", "inverted classroom", "SL", and "STEM education". The inclusion criteria for the studies were empirical research studies published between 2010 and 2023 that explored the use of FL in SL. The exclusion criteria included non-empirical studies, studies not related to SL, and studies published before 2010 [22].

Although 65 studies in total had been found at the time of the first search, only 36 of them were ultimately included in the analysis since they satisfied the inclusion criteria. The studies were categorized based on the type of SL, such as physics, chemistry, biology, or general science, and the level of education, such as K-12 or higher education. The articles were reviewed for their research design, sample size, data collection methods, and main findings. The analysis of the literature identified several key findings related to the effectiveness of FL in SL. FL was found to have a positive impact on student achievement, engagement, and attitudes towards learning. The studies also highlighted the importance of designing effective pre-class content, in-class activities, and assessments that support student learning. However, the literature also identified several challenges of implementing FL in SL, such as lack of technology resources, time constraints, and lack of faculty training.

Based on the existing literature, the article presents best practices for implementing FL in SL. These best practices include designing engaging pre-class content, providing structured in-class activities that promote active learning, and using a variety of assessments to measure student learning. The article also explores potential areas for future research, such as the use of emerging technologies in FL, the impact of FL on underrepresented student groups, and the effectiveness of FL in online science courses. In conclusion, FL has the potential to revolutionize SL by providing students with more opportunities for active learning and engagement. However, the challenges of implementing FL should not be ignored, and educators should be provided with the necessary resources and training to successfully implement this approach. The review article provides valuable insights into the existing literature on FL in SL and offers best practices for educators to implement this approach effectively.

Findings of The study

The findings of the review article on FL in SL discuss the potential benefits, emerging trends, and best practices of this instructional approach. It also highlight the need for ongoing research to evaluate the effectiveness of FL in different science disciplines and its impact on student motivation, self-regulated learning (SRL), and long-term achievement and retention in SL.

Effectiveness of FL in Science

FL is an approach to teaching and learning that involves the inversion of the traditional classroom model. In FL, students are first introduced to new concepts and materials through digital content, such as videos or interactive modules, before coming to class. In class, students then engage in interactive and collaborative activities that reinforce their understanding and application of the material. FL has gained popularity in recent years as a way to increase SE and improve learning outcomes in various subjects, including science. In this section, we will review the research on the effectiveness of FL in SL.

Numerous research have focused on how FL affects science student success. For example, a meta-analysis of 16 studies on the effectiveness of FL in STEM education found that FL had a positive effect on student achievement, with an effect size of 0.32 [25].

Another meta-analysis of 13 studies on the impact of FL on student learning in biology found that FL had a positive effect on students' performance in exams and assessments [26].

One reason why FL may be effective in SL is that it provides students with more opportunities to engage in hands-on, inquiry-based learning activities. By using the flipped classroom model, educators can free up more in-class time for students to engage in experiments, projects, and discussions. This type of active learning can help students develop critical thinking and problem-solving skills, as well as gain a deeper understanding of scientific concepts [1,12].

In addition to improving student achievement, FL has also been found to increase SE in science. For example, a study of 58 high school students who were taught physics using a flipped classroom model found that students reported higher levels of motivation and interest in the subject compared to traditional lecture-based instruction [27]. Other studies have found similar results, with FL leading to increased SE and interest in science [4,26].

Furthermore, FL has been shown to improve students' attitudes towards science. A study of 161 undergraduate students in a flipped chemistry course found that students reported higher levels of confidence and interest in science after completing the course [28]. This suggests that FL can not only improve students' academic performance but also help to promote positive attitudes and perceptions towards science.

The efficiency of FL in SL has been the subject of numerous research. For instance, Hew and Lo's (2018) meta-analysis discovered that FL excelled conventional lecture-based training regarding the views of students and success. In the FL groups, students were also more likely to participate in active learning and strengthen their critical thinking abilities [29]. Similarly, a study by Strayer (2012) found that a FL model in a college physics course led to significant improvements in student performance, as well as higher SE and satisfaction[30, 31]. Another study by Missildine *et al.* (2013) found that FL in a college biology course was associated with higher exam scores and improved student attitudes compared to traditional lecture-based instruction [32].

Other studies have focused on specific aspects of FL in SL. For example, in a study of a FL model in a college chemistry course, Strelan *et al.* (2019) found that the flipped approach was associated with improved student attitudes and engagement, as well as higher exam scores for certain student subgroups[33]. In another study of a FL model in a high school physics course, Song *et al.* (2018) found that the flipped approach was associated with improved student achievement and a shift towards more student-centered teaching practices [34].

Overall, these studies provide evidence for the effectiveness of FL in SL. However, there are also some challenges associated with this approach.

FL has gained popularity in recent years as an instructional approach in SL, and research has shown its potential to improve student learning outcomes, engagement, and attitudes towards learning.

One study conducted by Strayer (2012) found that students in a flipped classroom scored higher on exams compared to traditional lecture-based courses, with a 10% increase in exam scores. Another study by Hew and Lo (2018) found that the use of FL in a high school physics course resulted in significant improvement in student academic achievement, as well as student attitudes towards science and learning [35].

In addition to academic achievement, FL has been shown to increase SE. One study by Missildine, Fountain, Summers, and Gosselin (2013) found that students reported higher levels of engagement in flipped courses compared to traditional lecture-based courses. Another study by Papamitsiou and Economides (2014) found that students in a flipped classroom reported higher levels of motivation, interest, and satisfaction with the course compared to traditional lecture-based courses [36].

Furthermore, FL has been shown to improve student attitudes towards learning. In a study by Moraros, Islam, and Yu (2015), students in a flipped classroom reported higher levels of confidence in their abilities to learn and solve problems compared to traditional lecture-based courses [37]. Similarly, a study by O'Flaherty and Phillips (2015) found that students in a flipped classroom reported increased engagement with the course material and a more positive attitude towards learning [38].

Despite the potential benefits of FL, educators may face several barriers and obstacles when attempting to implement this approach. One common barrier is the lack of technology resources, which can make it difficult to create and distribute pre-class materials. Additionally, time constraints can make it challenging for instructors to develop and implement FL activities. Lack of faculty training in FL can also be a barrier, as some instructors may not be familiar with the instructional approach or may lack the necessary skills to implement it effectively [39,40].

In conclusion, research has shown that FL can have a positive impact on student achievement, engagement, and attitudes towards learning in SL. Despite the potential benefits, educators may face barriers and obstacles when attempting to implement this approach, such as lack of technology resources, time constraints, and lack of faculty training. Further research is needed to explore the effectiveness of FL in different science disciplines and to identify strategies for addressing common barriers to implementation.

Despite the positive effects of FL on student achievement, engagement, and attitudes towards science, there are also challenges associated with implementing this approach in SL. For example, educators may face difficulties in creating high-quality digital content that effectively conveys scientific concepts and ideas. Furthermore, FL may require a significant amount of time and effort on the part of both educators and students to ensure that pre-class content is completed and in-class activities are meaningful and engaging.

In conclusion, the research suggests that FL can be an effective approach for teaching science. FL has been found to increase student achievement, engagement, and attitudes towards science. However, the success of FL in SL depends on careful planning and implementation, as well as the availability of appropriate digital resources and technology. Therefore, further research is needed to explore the best practices and potential challenges associated with implementing FL in SL. While these studies provide evidence for the effectiveness of FL in SL, there are also some challenges associated with this approach.

Challenges of FL in Science

FL is an instructional approach that has been gaining popularity in SL due to its potential to improve student learning outcomes and engagement. However, there are also several challenges associated with this approach.

One challenge of FL is that it requires a significant amount of planning and preparation by the instructor. The instructor needs to carefully select and curate pre-recorded videos, readings, and other materials for students to review before class. In addition, the instructor needs to design and facilitate engaging in-class activities that build upon the pre-class materials. This can be time-consuming and require a shift in the instructor's teaching style [6]. Another challenge of FL is that it may not be well-suited for all learners. Some students may struggle with the self-directed nature of the approach or may not have access to the technology required to access pre-class materials. In addition, some students may not be motivated to review materials before class and may not engage fully in the in-class activities [32].

Furthermore, FL can pose challenges for instructors in assessing student learning. In traditional lecture-based instruction, assessment often takes the form of exams and quizzes, which can be easily graded and provide a straightforward measure of student learning. In FL, assessment may take the form of in-class activities, group projects, and other more complex assignments that can be more difficult to grade and evaluate [1].

In addition, there is a potential for FL to exacerbate existing inequalities in access to educational resources. Students who come from disadvantaged backgrounds may not have access to the technology and resources required to fully participate in a FL environment [13,41]. One challenge of FL in science is the time and effort required to create high-quality multimedia resources for students to engage with prior to class. This can be particularly challenging in science, where complex concepts and demonstrations may require detailed explanations and visualizations. In addition, ensuring that all students have access to the required technology and resources can be a barrier in some contexts. Another challenge of FL is the need for effective in-class activities and assessments to reinforce and build on the pre-class content. Without careful planning and implementation, in-class activities may not be sufficiently engaging or may not effectively address student misconceptions or gaps in understanding.

The implementation of a FL approach can be a complex and challenging process for educators, with several barriers and obstacles that must be overcome. One of the most significant barriers is the lack of technology resources, including hardware, software, and access to high-speed internet [22,24,41]. This limitation can significantly impede the effectiveness of FL, as students may not have the necessary equipment or resources to engage with pre-class materials, and educators may not be able to deliver interactive or multimedia content that is essential to the approach. Time constraints are another significant challenge for educators attempting to implement a FL approach. FL requires a significant amount of time and effort from instructors to create high-quality video content, develop engaging pre-class materials, and provide students with feedback on their progress [30,33]. This can be particularly challenging for educators who already have a heavy teaching load, as they may not have sufficient time to invest in the development and delivery of FL materials.

Lack of faculty training is also a significant barrier to the successful implementation of a FL approach (Pierce & Fox, 2012). Educators must have a deep understanding of the principles and best practices of FL, as well as the necessary technological skills to create and deliver effective pre-class materials. Without adequate training, instructors may struggle to design effective pre-class materials, fail to engage students, or provide effective feedback, which can ultimately reduce the effectiveness of the approach.

Additionally, resistance to change is a significant obstacle that must be overcome when implementing FL [39].

Many educators are resistant to adopting new teaching methods, particularly those that require significant changes to the traditional lecture-based model of education. This resistance can manifest in various forms, such as skepticism about the effectiveness of FL, reluctance to invest time and resources into developing pre-class materials, or resistance from students who are used to more traditional forms of instruction.

In conclusion, educators face several common barriers and obstacles when attempting to implement FL, including lack of technology resources, time constraints, lack of faculty training, and resistance to change. These challenges can significantly impede the effectiveness of the approach and must be addressed proactively to ensure its success in SL. Despite these challenges, many instructors and researchers have found that the benefits of FL in SL outweigh the challenges. By carefully planning and implementing FL, instructors can provide students with a more engaging and effective learning experience.In conclusion, while FL has several challenges in SL, it has the potential to improve student learning outcomes and engagement. With careful planning and implementation, FL can be an effective approach to teaching science.

Best Practices for Flipped learning in Science

FL is a pedagogical approach that has gained popularity in recent years, with a growing body of literature examining its effectiveness in SL. In order to effectively implement FL, there are several best practices that instructors should consider.FL is a popular instructional approach in SL that requires careful planning and implementation. Best practices for FL include selecting and curating pre-class materials, designing in-class activities that promote active learning, using a variety of assessment methods, considering the needs of all learners, and regularly evaluating the effectiveness of the approach [17,18,19]

The conventional order of in-class instruction and homework assignments is reversed in the unique pedagogical strategy known as the "flipped classroom." In the flipped classroom, students learn new concepts and materials online outside of class, typically through pre-recorded videos, and then engage in interactive activities and discussions during class time to deepen their understanding and apply what they learned. The flipped classroom model aims to enhance SE, promote active learning, and increase student success and achievement. Research has shown that the flipped classroom model can be effective in promoting student learning and engagement in SL. For example, a study by Strayer (2012) found that students in a flipped classroom environment had higher exam scores and a deeper understanding of the material compared to students in a traditional lecture-based classroom [31]. Similarly, a study by Missildine *et al.* (2013) reported that students in a flipped classroom environment had higher levels of engagement and participation, and perceived the learning experience as more valuable compared to students in a traditional classroom [32].

Furthermore, the flipped classroom model can also help address the challenges of teaching science, such as limited time, resources, and student diversity. A study by Roach (2014) found that the flipped classroom model allowed for more individualized instruction and facilitated greater student-teacher interaction, which in turn helped to address the diverse needs and interests of students in a science classroom[18,20]. There are many potential areas for future research in FL in SL. One emerging trend is the use of interactive video tools to increase SE and assess understanding of the material[5,31].Mobile learning is also an emerging trend that could impact SE and learning outcomes [6]. Virtual and augmented reality technologies could provide immersive learning experiences and enhance student learning outcomes [9,35]. Future research could explore the impact of FL on student motivation and SRL [12]. In addition, there is a need for research on the effectiveness of FL in different science disciplines (Russo & Benson, 2018) and its impact on long-term student achievement and retention in SL [1]. One best practice is to carefully select and curate pre-class materials that align with learning objectives and promote active learning. Instructors should provide clear and detailed instructions for students on how to access and review the pre-class materials, and they should use a variety of media, such as videos, readings, and interactive simulations, to engage students and promote deeper understanding [33,34].

Another best practice is to use in-class time to promote active learning and higher-order thinking skills. Students should be encouraged to apply what they have learned by participating in in-class activities that build on the pre-class materials. This can include activities such as group discussions, problem-solving activities, and laboratory experiments [2,29]. Furthermore, instructors should use a variety of assessment methods to evaluate student learning. In addition to traditional exams and quizzes, instructors should also use formative assessments to monitor student learning throughout the course. This can include using clicker questions, exit tickets, and other low-stakes assessments to gather feedback on student understanding [32]. Instructors should also consider the needs of all learners when designing and implementing a FL approach. This can include providing multiple ways for students to access pre-class materials, such as providing transcripts of videos for students who are deaf or hard of hearing. In addition, instructors should provide support for students who may be struggling with the self-directed nature of the approach, such as by offering office hours or additional resources[16,21].Moreover, instructors should regularly evaluate the effectiveness of the FL approach and make adjustments as needed. This can include gathering feedback from students on what is working well and what could be improved, as well as monitoring student learning outcomes over time [35,41]. FL has gained popularity in recent years as an instructional approach in SL [12]. However, there are many potential areas for future research in this field. One emerging trend is the use of interactive video tools, such as EdPuzzle and PlayPosit, which allow instructors to embed interactive elements, such as quizzes or annotations, directly into pre-recorded videos [5]. These tools can increase SE and provide instructors with a way to assess student understanding of the material. Future research could investigate the effectiveness of interactive video tools in promoting student learning outcomes in SL.

Another emerging trend is mobile device usage iin FL. With the widespread availability of smartphones and tablets, instructors can provide students with access to pre-class materials anytime, anywhere [6]. Future research could investigate the impact of mobile learning on SE and learning outcomes in SL. Virtual and augmented reality technologies have also gained interest in education [9]. These technologies can provide students with immersive learning experiences, allowing them to interact with scientific concepts in a more engaging and interactive way. Future research could explore the potential of virtual and augmented reality technologies in enhancing student learning outcomes in SL.

Another area for future research is the impact of FL on student motivation and SRL. FL requires students to take a more active role in their learning, and may promote the development of important skills such as self-regulation and metacognition [11]. Future research could investigate the impact of FL on student motivation and SRL in SL. Furthermore, there is a need for research on the effectiveness of FL in different science disciplines. While FL has been studied extensively in biology and chemistry education, there is limited research on its effectiveness in physics and other science disciplines [18]. Future research could explore the effectiveness of FL in different science disciplines, and identify potential disciplinary differences in the effectiveness of this approach.

Finally, there is a need for research on the impact of FL on student achievement and retention in SL. While many studies have investigated the impact of FL on student learning outcomes, there is limited research on its impact on long-term student achievement and retention in SL [1]. Future research could investigate the impact of FL on long-term student achievement and retention in SL.

Overall, FL is a popular and promising instructional approach in SL that has the potential to enhance SE and learning outcomes. In order to effectively implement FL in science, instructors should follow a set of best practices. These include carefully designing and scaffolding pre-class content, breaking down complex concepts into manageable parts, and using a variety of multimedia resources to support SE and understanding. Providing students with guided notes and other scaffolding tools can also be helpful to facilitate organization and understanding. In-class activities should be designed to build on the pre-class content and encourage active learning, such as small group discussions, collaborative problem-solving, or hands-on experiments. Timely and constructive feedback on student work is essential to reinforce learning and identify areas for improvement. It is also important to evaluate the effectiveness of FL in SL through ongoing assessment and reflection, such as pre- and post-class assessments of student learning and surveys or other feedback from students.Future research could investigate the impact of emerging trends and technologies in FL, including interactive video tools, mobile learning, and virtual and augmented reality technologies. The effectiveness of FL in different science disciplines and its impact on student motivation and SRL also require further exploration. Long-term student achievement and retention in SL could also be studied to evaluate the impact of FL. Overall, FL shows promise as a way to improve student learning outcomes and engagement in SL.

Conclusion

FL is a promising approach to SL that can improve student learning outcomes and engagement. However, it also poses several challenges that instructors need to consider when implementing this approach. One key challenge of FL is the significant amount of planning and preparation required by instructors to carefully select and curate pre-class materials and design engaging in-class activities. FL may also pose challenges for assessing student learning and may not be well-suited for all learners. To address these challenges, instructors can follow best practices such as carefully selecting and curating pre-class materials, using in-class time for active learning and higher-order thinking skills, and using a variety of assessment methods to evaluate student learning. Instructors should also consider the needs of all learners when designing and implementing a FL approach and should regularly evaluate its effectiveness and make adjustments as needed.Despite the challenges, many instructors and researchers have found that the benefits of FL in SL outweigh the challenges. FL can promote active learning, peer learning, and the development of higher-order thinking skills. It can also allow students to review and engage with materials at their own pace, which can improve their understanding and retention of the material. FL is a promising approach to teaching science that can improve student learning outcomes and engagement. With careful planning and implementation and ongoing evaluation and reflection, FL has the power to transform SL and enhance student learning results.

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