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Designing a self-regulated flipped learning approach to promote students' science learning performance

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ABSTRACT: Flipped learning, a well-established method in science education, sees its impact further amplified when coupled with the active control of self-regulated learners over their learning and metacognitive processes. In this study, a self-regulated flipped learning approach was designed and tested with the intention of enhancing the science learning performance of middle school students. A quasi-experimental design was employed involving middle school students from a science course in Turkey, with the aim to examine the impacts of the approach on students' academic achievements, attitudes, self-regulation levels, and motivations. The experimental group consisted of 29 students (14 male, 15 female) in the self-regulated flipped class, while the control group comprised 30 students (13 male, 17 female) who received traditional flipped learning instruction. In total, 59 eighth-grade students participated in the four-week study. Data were collected through achievement tests, attitude scales, self-regulated learning scales, and motivation scales. The results reveal that the experimental group outperformed the control group in terms of academic achievement, attitudes, self-regulated learning, and motivation. These findings can provide valuable insights and practical implications for educators and researchers in the fields of educational technology and science education.

Keywords: Self-regulated learning, Flipped learning, Science education, Middle school students

1. Introduction

Flipped learning (FL) represents an innovative pedagogical strategy that restructures conventional teaching paradigms by shifting direct instruction to outside the classroom and dedicating class time to active learning and problem-solving activities (Johnson & Renner, 2012). In recent years, FL has been acclaimed for its efficacy in augmenting learning outcomes (Bergmann & Sams, 2012; Kazeminia et al., 2022; Nja et al., 2022). By allowing students to delve into course content at their preferred pace prior to class, FL cultivates a student-centric environment that promotes collaboration and critical thinking (Chen et al., 2022; Tucker, 2012). Self-regulated learning (SRL) is an imperative educational construct that embodies the process wherein students actively govern their cognition, learning behaviors, and motivation (Panadero, 2017; van Alten et al., 2020a). By engaging in SRL, students can gain a deeper comprehension of intricate subjects and proficiently navigate challenges (Järvelä et al., 2015). This method encourages learners to set individual objectives, devise their learning strategies, monitor progress, and recalibrate their efforts as needed (Zimmerman, 2002). As the requirements of the 21st-century workforce continue to transform, fostering SRL in educational settings can equip students with vital skills that extend beyond the classroom, thereby preparing them for an ever-changing world.

The amalgamation of these two strategies within a self-regulated flipped learning (SRFL) framework can amplify students' learning experiences and outcomes by fostering autonomy and encouraging active participation in the learning process (Lai & Hwang, 2016). The integration of SRL within the FL approach can further enhance its efficacy by enabling students to take control of their learning processes and cultivate essential metacognitive skills (Kim et al., 2021; Jung et al., 2022; Silverajah et al., 2022; van Alten et al., 2020a; Yoon et al., 2021). This symbiosis between FL and SRL not only boosts learning outcomes but also heightens students' self-efficacy, time management, and study strategies (Çakıroğlu & Öztürk, 2017; Lai & Hwang, 2016). The incorporation of SRL into FL has yielded positive results across diverse fields including mathematics education (Lai & Hwang, 2016; Sun et al., 2018), history education (van Alten et al., 2020b), medical education (Zheng & Zhang, 2020), music teacher education (Montgomery et al., 2019), education for English as a foreign language (Öztürk & Çakıroğlu, 2021), programming language education (Çakıroğlu & Öztürk, 2017), and science education (Sletten, 2017).

Within this assortment, science education holds an important position in encouraging students' SRL (Winne, 2022) and designing flipped instruction (González-Gómez et al., 2016; Jdaitawi, 2020). Prior studies have revealed that self-regulated science instruction effectively fosters achievement and promotes self-regulation across primary, secondary, and higher education levels (Devolder et al., 2012; Fang et al., 2022; Maison & Syamsurizal, 2019; Schraw et al., 2006; Stevenson et al., 2017). Concurrently, FL has gained prominence in science education due to its potential to enhance academic outcomes (Bergmann & Sams, 2012; Kazeminia et al., 2022; Nja et al., 2022). By inverting traditional instructional methods and assigning lectures as homework while dedicating class time to problem-solving, FL fosters a profound understanding of scientific concepts (Abeysekera & Dawson, 2015; Gao & Hew, 2022). This learner-centered approach encourages active participation and collaboration (Chen et al., 2022; Tucker, 2012), leading to improved retention and critical thinking skills (Chen et al., 2022; Mazur, 2009). Despite these positive findings, Chen et al. (2022) have underscored the limited availability of research involving middle school students and countries outside of the USA. To bridge this gap and better understand FL's global applicability, further investigation is necessitated, especially within diverse educational contexts and across varied age groups.

There is a dearth of studies examining the SRFL in science education, which integrates self-regulated science learning into FL, thereby fostering students' academic cognition, motivation, and behaviors (Sletten, 2017). To bridge this gap, the current study seeks to test the self-regulated flipped learning approach (SRFLA) proposed by Lai and Hwang (2016) by implementing a middle school science topic in Turkey. The study aims to assess middle school students' learning performance, attitudes, SRL levels, and science learning motivation. The following research questions were explored:

- Do students who engage in the SRFLA achieve significantly more success than those who learn with the standard FL approach?
- Do students who engage in the SRFLA demonstrate significantly more positive attitudes towards science learning than those who learn with the standard FL approach?
- Do students who engage in the SRFLA display higher levels of self-regulation than those who learn with the standard FL approach?
- Do students who engage in the SRFLA exhibit a higher degree of motivation for science learning than those who learn with the standard FL approach?

2. Literature review

2.1. Flipped learning

FL encompasses a broad spectrum of instructional techniques that are applied distinctively by different educators and researchers (Leo & Puzio, 2016). Bergmann and Sams (2012) explain that in a flipped classroom, students engage with instructional videos or other learning materials at home prior to attending class. Class time is consequently used for problem-solving, collaborative activities, and projects, allowing teachers to provide personalized support and guidance tailored to each student's individual needs, thereby fostering active learning. Bishop and Verleger (2013) further characterize the flipped classroom as an innovative instructional strategy that melds asynchronous video lectures and practice exercises assigned as homework with active, group-oriented problem-solving activities conducted within the classroom. They also assert that this methodology uniquely amalgamates seemingly incompatible learning theories, incorporating both active, problem-based learning based on constructivist principles and instructional lectures derived from behaviorist direct instruction methods.

FL aspires to enhance the classroom environment's efficacy by engaging students in quality interactions with both teachers and peers, facilitating profound learning (Jong, 2017; Jong, 2019; O'Flaherty & Phillips 2015). Within the FL paradigm, course content is made accessible for students' perusal, followed by active guidance from teachers in problem-solving, leading discussions, and enriching students' learning experiences (Hao & Lee, 2016). Classroom learning may comprise a diverse array of educational activities such as teaching laboratory courses (Elkhatat & Al-Muhtaseb, 2021), reflection (Talley & Scherer, 2013), game-based learning (Hwang, & Chang, 2023; Parra-González et al., 2020; Tao et al., 2016), demonstrations (Gupta, 2020), discussions (Bognar et al., 2019), and small group projects (Ramnanan & Pound, 2017). Beyond the classroom, the learning process extends to various educational activities such as using videos, readings, quizzes, discussions, PowerPoint presentations, and online modules (Akçayır & Akçayır, 2018).

FL offers several potential benefits to students (Giannakos et al., 2014), teachers (Al-Naabi et al., 2022), and researchers (Karabulut-Ilgu et al., 2018). According to Akçayır and Akçayır (2018), these advantages can be categorized into six domains: learner outcomes, pedagogical contributions, dispositions, interaction, time efficiency, and miscellaneous benefits. Learner outcomes include improvements in student learning processes such as satisfaction, performance, and engagement levels. Pedagogical contributions provided by FL include the enhancement of flexibility and individualized learning in the educational process. Furthermore, FL enables both teachers and students to use their time efficiently, fosters positive attitudes towards the learning process, and improves the interaction between students and teachers. However, alongside its benefits, FL also presents certain challenges. Akçayır and Akçayır (2018) classify these challenges into five categories: pedagogical, students' and teachers' perspectives, technical & technological, and other miscellaneous issues. Among these, the most common challenge lies in out-of-class activities, specifically the limitations in student preparation during the teaching process. Additionally, time consumption emerges as a frequent concern expressed by both students and teachers. A considerable number of studies report that teachers often encounter technical issues during FL, such as video quality. Another challenge is that students sometimes struggle with transitioning between in-class and out-of-class environments (Wanner & Palmer, 2015).

FL has garnered significant interest within the realm of science education due to its unique pedagogical approach (Alrashed & Bin, 2021). An examination of research concerning FL within science education indicates that students' learning outcomes, perceptions, and attitudes represent primary foci for researchers (Chen et al., 2019). Considering that FL constitutes a relatively novel instructional methodology, comprehending its influence on students' academic performance and perspectives is pivotal for its successful incorporation. Various studies have confirmed the positive impact of FL on multiple aspects of science education, including students' academic performance, collaboration, communication, and higher-order cognitive skills (Canelas et al., 2017; Olakanmi, 2017). Additionally, FL appears to enhance students' perceptions of learning and motivation levels (Aşıksoy & Özdamlı, 2016; Sezer, 2017).

One facet of FL that has attracted considerable attention is students' learning behavior, particularly during the pre-class stage (Chen et al., 2019). Despite established evidence confirming the effectiveness of FL, the concerns of researchers and educators persist regarding students' learning status during this crucial phase. Studies exploring correlations or causality have demonstrated that students' engagement significantly influences their academic performance (Gross et al., 2015), indicating that learning behaviors in the pre-class stage substantially impact students' overall performance. A recent literature review conducted by Turan (2023) explored whether FL enhances student learning in science education and analyzed 64 studies. The results, aligned with the findings frequently emphasized in prior research, revealed that FL improves students' academic performance in science, fosters positive attitudes, perceptions, and views towards science, reduces withdrawal rates, boosts motivation, enhances student satisfaction and engagement, facilitates comprehensive understanding, and positively influences students' emotions. Nonetheless, while FL produces successful outcomes, social interactions between students and teachers remain insufficient, necessitating SRL that enables students to orchestrate their learning processes (Broadbent & Poon, 2015).

The interplay between FL and SRL is of considerable importance, as it significantly influences students' success in a FL environment (Shyr & Chen, 2018). SRL refers to students' capacity to orchestrate their learning processes, encompassing planning, monitoring, and reflecting on their learning activities (Zimmerman, 2002). Self-regulating students can set goals, select appropriate strategies, monitor their progress, and evaluate their learning outcomes (Pintrich, 2004). Given that FL environments necessitate students' active participation in their learning, SRL emerges as a crucial determinant of success in FL (O'Flaherty & Phillips, 2015). In a FL environment, SRL is indispensable for students to profit from both in-class and out-of-class learning activities. For instance, students must effectively plan and manage their time to engage with pre-class materials and partake in in-class activities (Akçayır & Akçayır, 2018). Moreover, self-regulation assists students in monitoring their learning progress and adjusting their strategies as necessary (Zimmerman, 2002), which is particularly important in a FL environment where students exercise greater autonomy over their learning (Yoon et al., 2020; Zainuddin & Perera, 2019).

Numerous studies have probed the relationship between FL and components of SRL. For instance, Silva et al. (2018) found that students in a FL environment exhibited enhanced levels of self-regulation, particularly in terms of planning and monitoring. Similarly, Çakıroğlu and Öztürk (2017) investigated the development of self-regulation in a flipped classroom setting employing problem-based learning activities and found that during face-to-face learning sessions designed with problem-based activities using the flipped classroom model, students displayed high levels of goal setting, planning, task strategies, and help-seeking skills. In at-home sessions, students exhibited high levels of environment structuring, goal setting, and planning skills. The study conducted by Sletten (2017) found that students' perceptions of the flipped model positively predicted their use of several types of SRL strategies. It was also observed that the success of flipped classrooms lies in active learning sessions facilitated by constructivist teaching methodologies. Although video lectures are an integral component of flipped classrooms, students may need to practice SRL skills to become more self-directed learners and to effectively engage with the video content.

2.2. Self-regulated learning

SRL, as defined by Pintrich (2000, p. 453), is "*an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by their goals and the contextual features in the environment*." Zimmerman and Schunk (2011, p.1) offer a similar definition, suggesting SRL as "*the process whereby learners personally activate and sustain cognitions, affects, and behaviors that are systematically oriented toward the attainment of learning goals.*" Zimmerman (2002) further divides SRL into three distinct phases: the forethought phase, the performance phase, and the self-reflection phase. During the forethought phase, students are tasked with analyzing learning assignments and determining specific goals and strategies to achieve these objectives (Lai & Hwang, 2016). The performance phase involves students in actively monitoring and controlling their learning progress (Moos & Bonde, 2016; Zimmerman & Moylan, 2009). Finally, the self-reflection phase necessitates students' evaluation of their learning efficiency and the effectiveness of the applied learning strategies (Lai & Hwang, 2016).

SRL significantly contributes to academic success (Cho & Shen, 2013; Littlejohn et al., 2016) and motivation (Michalsky & Schechter, 2013), as it enables students to manage their learning plans, fuel their learning motivation, and adjust learning strategies as needed (Butler & Winne, 1995; Heikkilä & Lonkab, 2006; Lai & Hwang, 2016). In the SRL process, cognitive, metacognitive, affective, and motivational elements play a pivotal role in propelling students' learning (Boekaerts, 1997). FL, renowned for its potential to foster SRL among students, can be synergistically integrated with SRL (Sun et al., 2018; Kim et al., 2021; Yoon et al., 2021; Zheng & Zhang, 2020). By encouraging students to actively participate in the learning process, FL can enhance the development of SRL skills, which are indispensable for both academic success and lifelong learning (Boyer et al., 2014; Zimmerman, 2002). FL empowers students to assume responsibility for their own learning (Bergmann & Sams, 2012). In this environment, students are expected to review course materials and engage in learning activities outside of class, preparing them for active in-class participation (Abeysekera & Dawson, 2015). This shift in responsibility promotes the application of SRL components, such as planning, goal setting, and the selection of appropriate learning strategies (Pintrich, 2000; Zimmerman, 2000). Furthermore, the FL environment provides opportunities for students to exercise SRL skills through various activities and assessments. Self-assessment tools, such as quizzes or reflection prompts, enable students to monitor their understanding and adjust their learning strategies accordingly (Fulton, 2012; Moos & Bonde, 2016). Through this monitoring process, students can develop a heightened metacognitive awareness, a vital aspect of SRL (Zimmerman, 2002). In addition, FL encourages reflection on learning experiences (Petichakis, 2022). By applying learned concepts through in-class activities, students can deepen their understanding and reflect on their learning journey (Howell, 2021; Lin et al., 2021). Such reflections help students to evaluate the effectiveness of their learning strategies, subsequently improving their SRL skills (Abeysekera & Dawson, 2015; Chen et al., 2019). Lastly, FL facilitates student-teacher interactions and peer collaborations, which can support the development of SRL (Bhagat et al. 2016; Lo & Hew, 2017). In an FL classroom, teachers can provide individualized guidance and feedback, enabling students to refine their learning strategies and evolve into more self-regulated learners (Moffett, 2015; Sletten, 2017; Wanner & Palmer, 2015). Group activities within an FL environment, such as projects or discussions, can promote social regulation of learning, a crucial aspect of SRL (Çakıroğlu, & Öztürk, 2017; Hadwin et al., 2011; Yoon et al., 2021). Given these significant advantages, the integration of FL and SRL has been the subject of increasing interest among researchers globally.

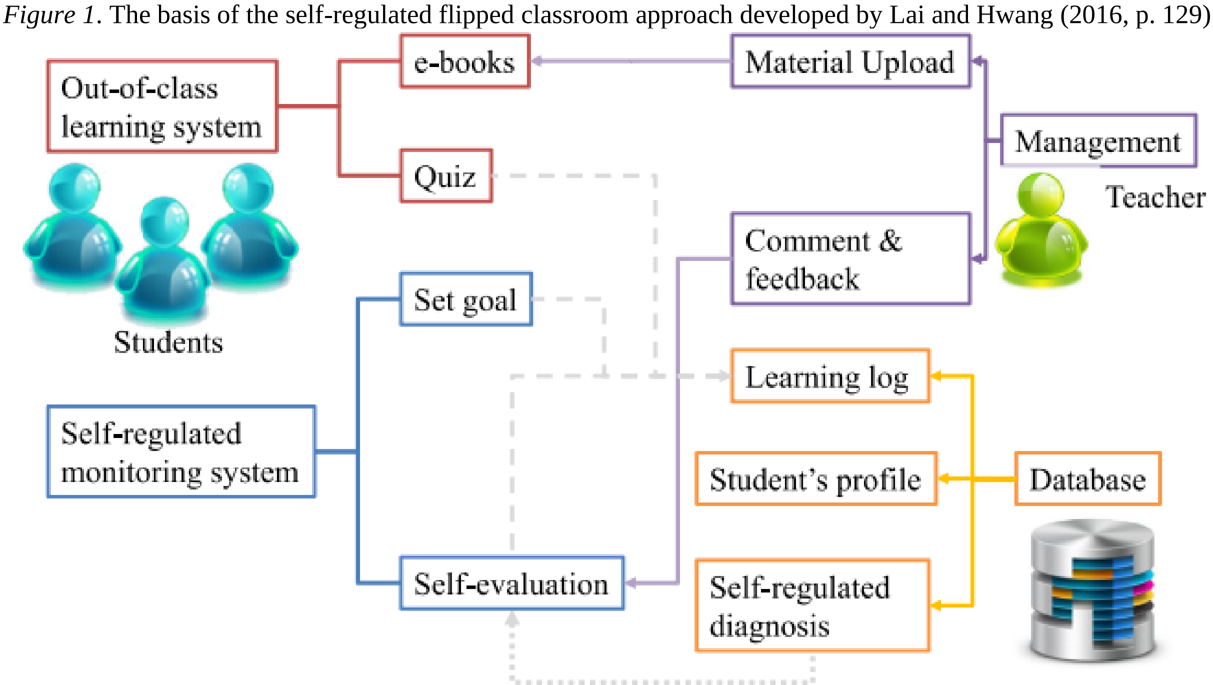
In a study spearheaded by Lai and Hwang (2016), a SRFLA was deployed to elevate the mathematical achievements of fourth-grade students in an elementary school in Taiwan. Findings revealed that students engaged in SRL demonstrated superior learning achievements and higher self-efficacy compared to those exposed to traditional FL design. Moreover, the approach was instrumental in enhancing students' abilities to plan and optimally utilize study time. Parallel outcomes were noted in a study by Yoon et al. (2021) conducted at a United States university, where FL was leveraged as a learning environment. The findings indicated that undergraduate students within the SRL group exhibited advanced SRL skills, improved learning performance, heightened behavioral engagement prior to class, and increased cognitive engagement during in-class sessions. These students also demonstrated increased emotional engagement before and after classes, compared to their counterparts in the non-SRL group. A separate study by Sun et al. (2018) examined the role of SRL in shaping students' success in mathematics within an FL context in the United States. The research affirmed that students' self-efficacy in a math course and their utilization of help-seeking strategies were positively correlated with their academic achievement. van Alten et al. (2020a) embarked on an empirical study scrutinizing the influence of SRL support on students' self-reported activities, online engagement, learning outcomes, and satisfaction in an eight-week flipped history course. Although the study concluded that SRL contributes significantly to students' academic success, it did not necessarily enhance their satisfaction levels. In light of these findings, the present study hypothesizes that middle school students possessing higher levels of self-regulation are likely to be more successful in a science course within an FL environment than those with lower levels of self-regulation. Consequently, the research aimed to assess the impact of the SRFLA on middle school students' academic achievement, attitudes, levels of SRL, and motivation within the sphere of science education.

2.3. Self-regulated flipped classroom approach

The Self-Regulated Flipped Classroom Approach (SRFLA), developed by Lai and Hwang (2016), was adapted for use in this study to support the learning activities within a flipped classroom context. The SRFLA comprises an out-of-class learning system, a self-regulated monitoring system, a teacher management system, and a database. The out-of-class learning system is equipped to provide students with e-books and quizzes, designed to be completed prior to in-class activities. In tandem, the self-regulated monitoring system is built to enable students to establish their learning objectives and assess their own performance. The teacher management system, on the other hand, allows educators to upload e-books and offer feedback to students. The database, a critical component of the SRFLA, is responsible for recording students' learning logs, maintaining profiles, and generating diagnostics based on the educator's criteria and the students' learning logs.

The learning process under the SRFLA commences with an introduction to the syllabus and a detailed explanation of the self-regulation and flipped classroom learning modes. Students then proceed to set learning goals based on their past experiences and utilize the out-of-class learning system to study e-books and attempt quizzes. Teachers, in their role, monitor students' learning logs and overall performance. They conduct discussions and offer supplementary knowledge during in-class activities. Post-lesson, students engage in self-evaluation, and the database, in turn, provides diagnostic insights based on their performance to make necessary adjustments to self-regulation. The goal-setting interface necessitates students to set specific goals related to their desired scores, time allocation, learning location, and strategies. After these goals are set, students access the e-books and complete the quizzes before in-class activities. The system logs the time spent and records quiz responses, facilitating both students and teachers to monitor performance. In-class activities are centered around discussing out-of-class learnings and providing extended instruction. Upon the completion of each unit, students perform self-evaluations, submitting their results, and reviewing teachers' feedback. The teachers' comments are crafted based on students' goals, actual scores, system recordings, and the criteria set by the teachers. The self-regulated diagnostic aspect encompasses performance management and self-evaluation. The system computes an individualized learning diagnosis for each student, delivering instantaneous personal diagnoses, which in turn enable students to self-reflect and establish goal-setting for the subsequent learning unit. The structure of the approach is depicted in Figure 1.

Figure 1. The basis of the self-regulated flipped classroom approach developed by Lai and Hwang (2016, p. 129)



3. Method

3.1. Research design

This study adopted a quasi-experimental design, incorporating a pre-test/post-test control group framework, in which participants were not randomly assigned to respective groups (Fraenkel et al., 2012). The design was implemented to compare the level of conceptual understanding among middle school students taught via a self-regulated flipped classroom approach, with those taught through the standard flipped classroom method.

3.2. Participants

Participants in this study were eighth-grade students from a middle school located in a mid-sized city in the central Anatolian region of Turkey. Characteristic of state schools, the majority of the students were from middle-income families. Notwithstanding, they encountered no technical impediments, such as access to a mobile device or an internet connection. As detailed in Table 1, the study comprised a total of 59 students (32 males, 27 females), aged between 13 and 14 years (M = 13.78, SD = 0.34). These students were allocated into either the control group (N = 30) or the experimental group (N = 29). The same teacher was entrusted with delivering the science instruction across both groups.

Table 1. Characteristics of participants in terms of gender and group

Gender	Experimental group	Control group
Female	14	13
Male	15	17
Total	29	30

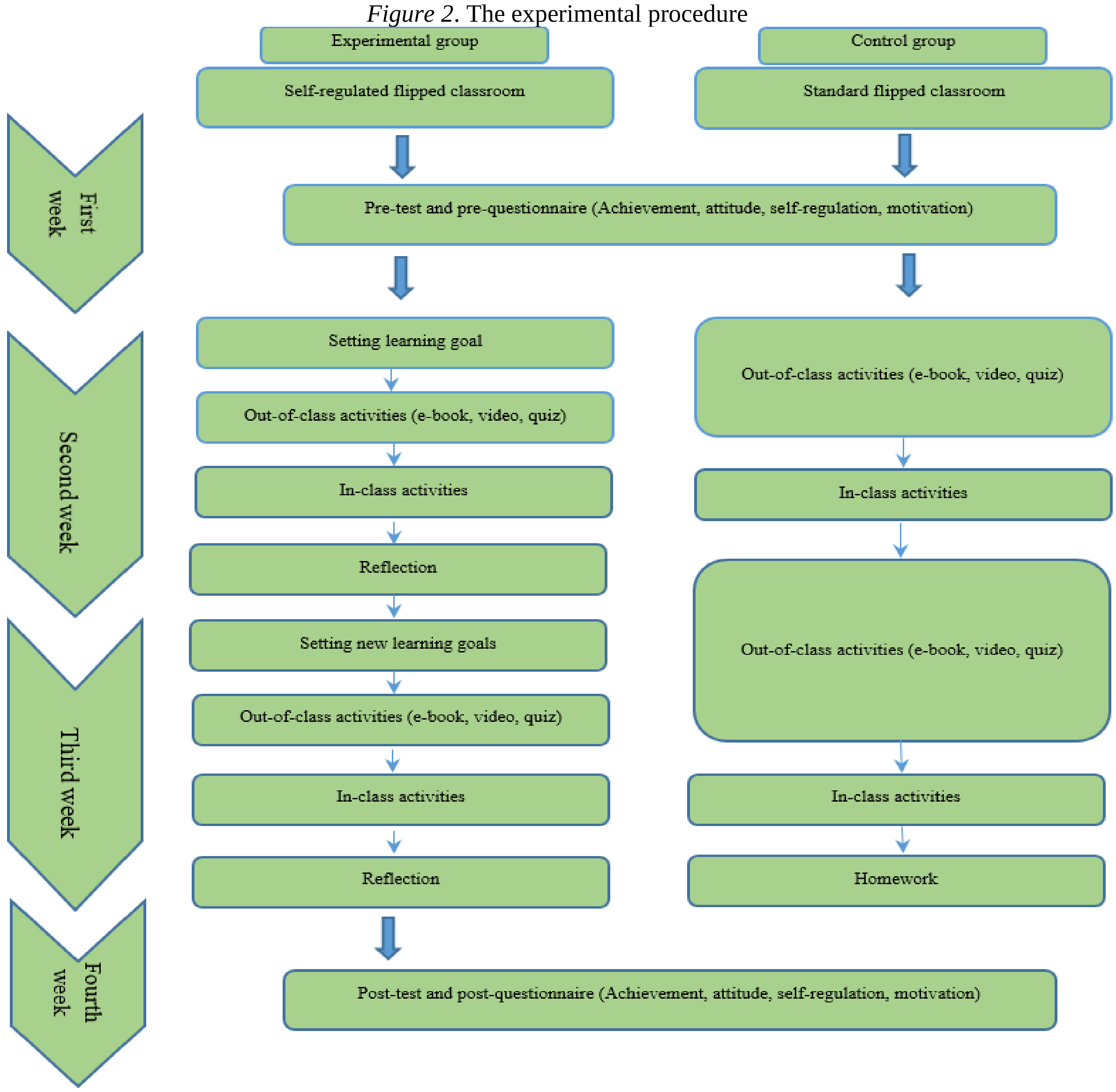
3.3. Experimental procedure

The study's experimental procedure was conducted within the framework of the "DNA and Genetic Code" unit for 8th-grade students during the 2022-2023 academic year. Before the study's commencement, comprehensive informed consent forms, outlining details of the students' participation, the voluntary nature of their involvement, the study's benefits and risks, any potential discomforts, confidentiality measures, and contact information were distributed to all participating students and their families. The procedure strictly complied with the science curriculum developed by the Turkish Ministry of National Education (2018). The students in the control group received instruction via the standard FL approach, while those in the experimental group participated in the SRFLA. The creation of technology tools spanned a period of seven weeks, succeeded by a four-week experimental process.

During the seven-week period, a comprehensive set of FL resources, including an e-book (see Figure 3), instructional videos (see Figure 4), and online quizzes (see Figure 5), were developed to cover the science topic at hand. The initial week involved rigorous research into the topics, leading to the formulation of an outline for the e-book and instructional videos. This included chapter titles, subheadings, learning objectives, and key concepts. From the second week through to the fourth week, the creation of content for the e-book chapters, instructional video scripts, and online quiz materials took place concurrently. In the fifth week, a thorough review and editing process was conducted for the e-book, instructional videos, and quizzes, to ensure clarity, coherence, and accuracy, integrating revisions based on feedback from peers and subject matter experts. The sixth week was devoted to designing the e-book layout, incorporating text formatting, illustrations, and diagrams, and adapting it for compatibility across various devices and platforms. Concurrently, the instructional videos underwent recording, editing, and finalization processes, with the integration of visuals, animations, and voiceovers to enrich the learning experience. The online quizzes were fine-tuned and tested for functionality, while all materials were compiled into a user-friendly platform for easy access and navigation. The seventh and final week entailed a thorough final review of the e-book, instructional videos, and online quizzes to ensure their accuracy, readability, and engagement potential. Once approved, these FL resources were hosted on designated learning platforms and disseminated to the intended audience.

The study's experimental procedure was carried out over a four-week period. To uphold the validity and reliability of the study, a series of experimental controls were applied. These included maintaining consistency in learning materials, the teacher's role, monitoring of out-of-class activities, pre-test and post-test measurements, the study's duration and sequence, and the employment of a quasi-experimental pre-test/post-test control group design. With the integration of these controls, the study strived to furnish a robust comparison of the SRFLA and the standard FL approach, thereby enriching the expanding corpus of research on FL in science education. During the first week of the experiment, the teacher elucidated the learning outcomes and expectations for the unit to the students, ensuring they understood the knowledge they were to acquire and the skills they were to develop throughout the unit. Each activity during this week was designed to span approximately four hours. The students were equipped with an e-book and instructional videos covering the subjects to be tackled during the unit. They also undertook the achievement, attitude, self-regulation, and motivation questionnaires as a pre-test. This design's rationale was to establish a foundational understanding of the students' existing knowledge and skills prior to engaging in FL and self-regulatory activities.

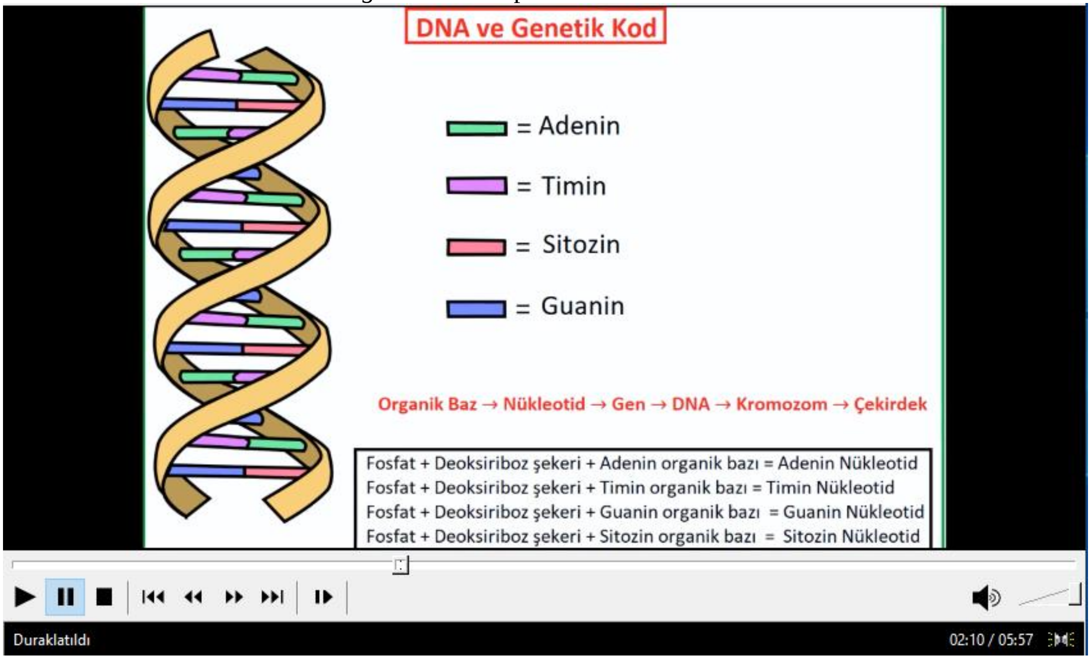
Figure 2. The experimental procedure



In the second and third weeks, the focus shifted towards the science topic, which included the structure of DNA, DNA replication, nucleotides, genes, and chromosomes. Each out-of-class activity was designed without a rigid time constraint, enabling students to learn at their own pace from home. This duration flexibility was intended to accommodate diverse learning styles and preferences, thereby fostering a more efficient learning experience for all students. Both the experimental and control groups partook in out-of-class activities, involving studying the e-book, viewing the instructional videos, and completing online quizzes. During this phase, the experimental group was directed to set learning goals and self-evaluate their progress, thereby encouraging self-regulation within the learning process. The teacher monitored the students' out-of-class activities to guarantee equal exposure to the learning materials and activities across both groups. The in-class activities during this week, designed to last approximately four hours, encompassed a brief review of the topics covered, followed by small-group problem-solving tasks constructed to stimulate critical thinking, collaboration, and application of the concepts learned. Consistent feedback was provided to both groups by the teacher, and the experimental group was encouraged to appraise and reflect on their learning, setting new goals for the subsequent week based on their reflections. The rationale behind this design was to blend the essential elements of FL, such as engaging students with content outside the classroom and promoting active learning, with self-regulated learning strategies like goal-setting and self-assessment.

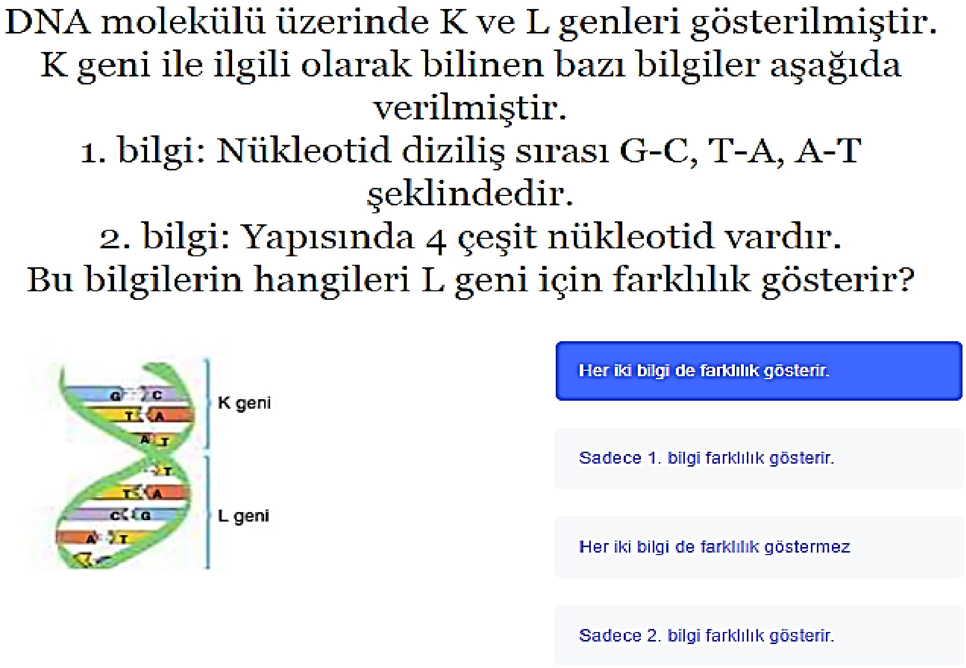
Figure 3. The user interface of the e-book

Figure 4. A sample instructional video



In the concluding week of the study, all students were required to complete achievement, attitude, self-regulation, and motivation questionnaires as post-tests. The purpose of this assessment was to identify any shifts in these domains as a consequence of the educational intervention. For consistency, each activity was meticulously scheduled to last approximately four hours. This exhaustive evaluation facilitated a more profound understanding of the SRFLA's impact on middle school students' academic achievement, attitudes, self-regulation, and motivation. Figure 2 outlines the four-week procedural framework used in conducting the study.

Figure 5. A sample question in the online quiz



3.4. Measures

Several scales were used for data collection in this study, including the achievement test, attitude scale, self-regulated learning (SRL) scale, and motivation scale.

3.4.1. Achievement test

The achievement test was designed to assess students' understanding of the "DNA and Genetic Code" unit. The unit aimed for students to acquire knowledge and skills related to DNA and genetic code, understand concepts like inheritance, mutation, modification, adaptation, selection, variation, genetic engineering, and biotechnology applications, and to discuss their positive and negative effects (Turkish Ministry of National Education, 2018). An achievement test was developed to evaluate the attainment of the unit's intended outcomes and was administered both before and after the experimental period. The test contained 25 multiple-choice items, derived from previous exams administered by the Turkish Ministry of National Education, with a maximum attainable score of 100. All students were administered the same achievement test. The test's reliability coefficient was found to be 0.82.

3.4.2. Attitude scale

The attitude scale, crafted by Oguz (2002), is unidimensional and gauges overall attitudes toward science. It comprises 20 items, rated on a 5-point Likert scale ranging from "Strongly Disagree" to "Strongly Agree." An exemplar item from the scale is "I like my science course." The scale has demonstrated a high level of internal consistency, with a Cronbach's alpha coefficient of 0.87. This unidimensional feature of the scale facilitates a focused analysis of students' overall attitudes towards science in the context of FL.

3.4.3. Self-regulated learning scale

The SRL scale, developed by Barnard et al. (2009), incorporates 24 items with a 5-point Likert-type scale ranging from strongly disagree (1) to strongly agree (5). The scale's reliability coefficient was calculated to be

0.89. The scale's original form consists of six sub-dimensions: "Goal Setting" (α = 0.92), "Environment Structuring" (α = 0.88), "Task Strategies" (α = 0.90), "Time Management" (α = 0.85), "Help Seeking" (α = 0.93), and "Self-Evaluation" (α = 0.91).

3.4.4. Motivated strategies for learning questionnaire

The Motivated Strategies for Learning Questionnaire (MSLQ), developed by Pintrich et al. (1991), assesses students' motivational orientations and their employment of various learning strategies. The MSLQ, with proven reliability and validity, has been extensively utilized for measuring motivational and SRL variables (Duncan & McKeachie, 2005). For this study, the MSLQ's "Intrinsic Goal Orientation" (α = 0.72), "Extrinsic Goal Orientation" (α = 0.75), "Task Value" (α = 0.88), and "Self-efficacy for Learning and Performance" (α = 0.83) constructs were employed, given their comprehensive coverage of SRL facets (van Alten et al., 2020a). Each construct contains four items rated on a 5-point scale, ranging from 1 (not at all true of me) to 5 (very true of me).

3.5. Data analysis

The data in this study were analyzed using the Statistical Package for the Social Sciences (SPSS), Version 22. Throughout the analytical process, Cronbach's alpha values were determined for each scale to assess reliability. Descriptive statistics were executed with the use of central tendency measures, such as the mean and standard deviation. In order to evaluate the differences between the control and experimental groups prior to the intervention, a one-way multivariate analysis of variance (MANOVA) was implemented. A two-way Analysis of Variance (ANOVA) was conducted to identify whether significant differences existed between the two teaching methods, namely the SRFLA and the traditional FL approach. Additionally, another two-way ANOVA was undertaken to assess differences between pre-test/questionnaire and post-test/questionnaire scores concerning the study's primary variables, which included achievement, attitudes toward science, self-regulation learning skills, and motivation. Lastly, the impact of the SRFLA on the sub-dimensions of "Self-Regulatory Learning Skills" and "Motivation" was examined using an independent sample t-test.

4. Results

4.1. Examination of pre-test score differences

In alignment with the foundational approaches of the quasi-experimental design, an initial analysis was carried out to determine whether a significant difference existed between the control group and the experimental group in the pre-tests and pre-questionnaires. A one-way MANOVA was conducted to investigate the potential difference between the control group and the experimental group in relation to pre-tests and pre-questionnaires, focusing on achievement, attitudes toward science, self-regulated learning, and motivation. The results indicated no significant difference between the conditions in pre-scale scores (F (6, 108) = 0.74, p = .619; *Wilk's Λ* = 0.961).

4.2. Effects of the self-regulated flipped learning

This study examined the effect of SRFLA on science achievement, attitude toward science, SRL, and motivation.

4.2.1. Biology achievement

The two-way ANOVA results revealed a statistically significant difference with respect to educational interventions (F = 9.018, p < .01) and students' biology achievement (F = 15.316, p < .01). Moreover, no significant interaction was found between these variables (F = 3.19, p > .05). The mean values and standard deviations of the post-test achievement scores were 84 and 5.79 for the experimental group, and 68 and 6.21 for the control group. These findings suggest that the SRFLA can enhance students' achievements more effectively than the traditional FL approach. Furthermore, the results demonstrated that students' biology achievement in the post-test scores was significantly higher than their pre-test scores, indicating that the SRFLA could improve students' biology achievement. Descriptive statistics and ANOVA results for students' biology achievements are presented in Tables 2 and 3.

Table 2. Descriptive statistics of the students' biology achievements of the two study groups

Achievement test	Experimental group			Control group		
	n	*M*	*SD*	*n*	*M*	*SD*
Pre-test	29	28	8.87	30	32	8.51
Post test	29	84	5.79	30	68	6.21

Table 3. The two-way ANOVA results of the achievement test and study groups in terms of post-test scores

Variables	*df*	*F*	*p*
Educational treatments	1	9.018	.005
Achievement	1	15.316	.001
Study groups ×Achievement	1	3.19	.12
Error	57		

4.2.2. Attitude toward science

The mean values and standard deviations of the post-questionnaire scores were 4.67 and 1.03 for the experimental group, and 4.19 and 1.12 for the control group. The experimental results revealed a significant effect between the experimental group and the control group (F = 12.33, p = .008). This indicates that students who learned using the SRFLA exhibited significantly higher attitudes toward science compared to those who learned through the traditional FL approach. Furthermore, the ANOVA results demonstrated a significant difference between pre-questionnaire scores and post-questionnaire scores (F = 11.14, p = .004), suggesting that the SRFLA effectively improved students' attitudes toward science. Nonetheless, no interaction was detected between the variables (F = 13.48, p = .19). Tables 4 and 5 present the descriptive statistics and two-way ANOVA results concerning students' attitudes toward science.

Table 4. Descriptive statistics of the students' attitudes toward science of the two study groups

Attitude toward science	Experimental group			Control group		
	n	*M*	*SD*	*n*	*M*	*SD*
Pre-test	29	3.52	1.18	30	3.47	1.22
Post test	29	4.67	1.03	30	4.19	1.12

Table 5. The two-way ANOVA results of the attitude scale

Variables	*df*	*F*	*p*
Study groups	1	12.33	.008
Attitude	1	11.14	.004
Study groups × Attitude	1	13.48	.19
Error	57		

4.2.3. Self-regulatory learning skills

The mean values and standard deviations of the self-regulatory learning skills for post-questionnaire scores were 4.01 and 1.30 for the control group, and 4.39 and 1.11 for the experimental group. The findings revealed a significant effect for teaching methods (F = 5.78, p = .007) and self-regulatory learning skills (F = 7.89, p = .003). These results suggest that learning through the SRFLA can enhance students' self-regulatory learning skills more effectively than the traditional FL approach. Additionally, the analysis indicated that students' self-regulatory learning skills significantly improved following the implementation of the teaching method. However, no significant interaction was observed (F = 9.12, p = .12). Tables 6 and 7 display the results of the descriptive statistics and the two-way ANOVA concerning students' self-regulatory learning skills.

To gain a deeper understanding of the students' self-regulatory learning skills with regards to sub-dimensions including environment structuring, goal setting, help seeking, self-evaluation, task strategies, and time management, an independent t-test was employed as indicated in Table 8. The results disclosed no significant disparity between the self-regulatory learning skills ratings for each dimension in the pre-questionnaire for the control and experimental groups (t_{range} = 0.89-2.42, p > .05), signifying that students in both groups possessed similar levels of self-regulatory learning skills before embarking on their flipped classroom. This study went a step further by juxtaposing the six dimensions of self-regulatory learning skills in the post-questionnaire.

Table 6. Descriptive statistics of the students' self-regulatory learning skills

Self-regulatory learning skills	Experimental group			Control group		
	n	*M*	*SD*	*n*	*M*	*SD*
Pre-test	29	3.42	1.27	30	4.29	1.47
Post test	29	4.39	1.11	30	4.01	1.30

Table 7. The two-way ANOVA results of the self-regulatory learning skills

Variables	*df*	*F*	*p*
Study groups	1	5.78	.007
Self-regulatory learning skills	1	7.89	.003
Study groups × Self-regulatory learning skills	1	9.12	.12
Error	57		

The statistical analysis revealed that students in the experimental group exhibited a significantly heightened awareness of goal setting (M = 4.20, SD = 0.55) in comparison to the control group (M = 3.65, SD = 0.50), t = 3.60, p = .001. Likewise, the experimental group demonstrated a markedly enhanced understanding of task strategies (M = 4.15, SD = 0.60) as opposed to the control group (M = 3.40, SD = 0.58), t = 4.25, p = .001. With regard to time management awareness, the experimental group (M = 4.05, SD = 0.62) significantly outperformed the control group (M = 3.45, SD = 0.57), t = 3.45, p = .002. Furthermore, the experimental group (M = 4.30, SD = 0.54) achieved notably higher scores in help-seeking awareness relative to the control group (M = 3.75, SD = 0.51), t = 3.85, p = .001. Lastly, in the dimension of self-evaluation, the experimental group (M = 4.10, SD = 0.59) significantly exceeded the control group (M = 3.55, SD = 0.56), t = 3.30, p = .003.

Table 8. Comparison of dimensions of self-regulatory learning skills between experimental and control groups

Dimension	Group	*M*	*SD*	*t*	*p*
Goal Setting	Experimental	4.20	0.55	3.60	.001
	Control	3.65	0.50		
Task Strategies	Experimental	4.15	0.60	4.25	.001
	Control	3.40	0.58		
Time Management	Experimental	4.05	0.62	3.45	.002
	Control	3.45	0.57		
Help-Seeking	Experimental	4.30	0.54	3.85	.001
	Control	3.75	0.51		
Self-Evaluation	Experimental	4.10	0.59	3.30	.003
	Control	3.55	0.56		

4.2.4. Motivation

Regarding motivation, as illustrated in Tables 9 and 10, the mean values and standard deviation were 4.59 and 1.42 for the experimental group, and 4.11 and 1.54 for the control group. The two-way ANOVA result revealed a significant difference in relation to the teaching method (F = 10.89, p = .009). Additionally, a significant difference was found between pre and post-questionnaires concerning students' motivations (F = 13.45, p = .005). These findings suggest that students who engaged in learning with the SRFLA exhibited higher motivation than those who participated in the traditional FL approach. Moreover, the results indicate that the SRFLA was more effective in enhancing post-questionnaire scores compared to pre-questionnaire scores. The study also determined that there was no significant interaction between the variables (F = 9.77, p = .09).

Table 9. Descriptive statistics of the students' motivations

Motivation	Experimental group			Control group		
	n	*M*	*SD*	*n*	*M*	*SD*
Pre-test	29	3.11	1.78	30	3.01	1.69
Post test	29	4.59	1.42	30	4.11	1.54

Table 10. The two-way ANOVA results of the motivations

Variables	*df*	*F*	*p*
Study groups	1	10.89	.009
Motivation	1	13.45	.005
Study groups × Motivation	1	9.77	.09
Error	57		

The *t*-test results comparing the sub-dimensions of motivation including "intrinsic goal orientation," "extrinsic goal orientation," "task value," and "self-efficacy for learning and performance" between the experimental and control groups are presented Table 11. The analysis was conducted using an alpha level of 0.01 to determine the significance of the differences between the two groups. Firstly, the analysis revealed a significant difference in intrinsic goal orientation between the experimental group (M = 4.25, SD = 0.65) and the control group (M = 3.70, SD = 0.62, t = 3.15, p = .003). This result suggests that the students in the experimental group had a higher level of intrinsic goal orientation compared to their counterparts in the control group. Secondly, the extrinsic goal orientation was found to be significantly different between the experimental group (M = 4.10, SD = 0.58) and the control group (M = 3.55, SD = 0.60, t = 2.90, p = .006). The experimental group displayed a stronger extrinsic goal orientation as opposed to the control group. In addition, the task value was significantly higher in the experimental group (M = 4.35, SD = 0.63) compared to the control group (M = 3.45, SD = 0.61, t = 4.05, p = .001). This finding indicates that students in the experimental group placed a greater value on the tasks than students in the control group. Lastly, a significant difference was observed in the self-efficacy for learning and performance between the experimental group (M = 4.20, SD = 0.67) and the control group (M = 3.50, SD = 0.64, t = 3.80, p = .001). Students in the experimental group demonstrated a higher level of self-efficacy for learning and performance as compared to their peers in the control group.

Table 11. Comparison of motivation sub-dimensions between experimental and control groups

Sub-Dimensions	Group	*M*	*SD*	*t*	*p*
Intrinsic Goal Orientation	Experimental	4.25	0.65	3.15	.003
	Control	3.70	0.62		
Extrinsic Goal Orientation	Experimental	4.10	0.58	2.90	.006
	Control	3.55	0.60		
Task Value	Experimental	4.35	0.63	4.05	.001
	Control	3.45	0.61		
Self-Efficacy for Learning & Performance	Experimental	4.20	0.67	3.80	.001
	Control	3.50	0.64		

5. Discussion and implications

The reviews by Chen et al. (2022) and Turan (2023) have indicated an increasing number of studies on the FL approach in science education in recent years. Prior research underscores the efficacy of the FL approach in enhancing students' science achievements, attitudes toward science, motivation, satisfaction, comprehension, and emotional engagement. However, as technological advancements and the evolving needs of students continue to shape science education, it becomes increasingly important for students to take charge of their learning processes (Ateş & Garzón, 2022; Ateş & Garzón, 2023; Zydney & Warner 2016). In light of this information, SRL makes significant contributions to fulfilling students' learning needs (van Alten et al., 2020a; Jdaitawi, 2020; Winne, 2022; Yoon et al., 2021), highlighting the necessity for further research aimed at enhancing students' SRL in science education. The study implemented a SRFLA for a middle school science course, with an experimental process that included an e-book, video, and quiz components. This approach enabled students to read course content from an e-book, view instructional videos, answer online quizzes, and consult with the course instructor via an instant messaging program. In-class activities included small group discussions and feedback sessions with the instructor. The control group followed a traditional FL approach.

The initial findings of this study affirm that the FL approach positively influences the learning process of middle school students, corroborating recent studies in the field of science education (e.g., Candaş et al., 2022; Lee et al., 2021; Nacaroğlu et al., 2023; Ugwuanyi, 2022). Further evaluation of the implemented SRFLA indicates a significant improvement in students' academic achievements and an enhancement in their attitudes towards science. Moreover, the SRFLA also bolstered students' SRL levels in areas such as goal setting, environment structuring, task strategies, time management, help-seeking, and self-evaluation. Additionally, this study furnishes empirical evidence highlighting the development of students' motivations, encompassing intrinsic goal orientation, extrinsic goal orientation, task value, and self-efficacy for learning and performance through this approach. In alignment with Zimmerman and Schunk's (2011) core concepts, the findings suggest that middle school students were successful in activating and sustaining their affective, cognitive, and behavioral systems oriented towards the achievement of learning objectives in the science course.

The conduct of the study reinforces the enduring theories of Pintrich et al. (1991) and Duncan and Mckeachie (2005), which advocate for the development of motivational orientations and the use of diverse learning strategies for science courses. These results are consistent with prior studies evaluating the impact of SRFL on students' learning processes (e.g., Çakıroğlu & Öztürk, 2017; Shibukawa & Taguchi, 2019; Shih & Huang, 2019; van Alten et al., 2020a; Zheng & Zhang, 2020). For instance, Lai and Hwang (2016) found that teaching in a self-regulated flipped classroom amplified students' learning achievements and self-regulated levels in a mathematics course. A comparable discovery by van Alten et al. (2020a) proposed that SRFL plays a pivotal role in enhancing students' learning and cultivating their awareness of their own learning process. A recent study by Kim et al. (2021) disclosed that SRL in the flipped classroom yields successful outcomes, ensuring student satisfaction and learning continuity.

In light of these findings, several practical implications can be derived to optimize science education, particularly in the context of evolving technology and the changing needs of students. Firstly, educators should consider incorporating SRFLA into their curriculum to improve students' learning outcomes. The use of e-books, instructional videos, and online quizzes in out-of-class activities allows students to control their learning and engage with the material at their own pace. Teachers can support this learning process by facilitating in-class activities, such as small group discussions, providing feedback, and creating a conducive learning environment. Additionally, teachers should emphasize the development of SRL skills in their students. Skills such as goal setting, environment structuring, task strategies, time management, help-seeking, and self-evaluation are crucial for students' academic success. By integrating these skills into the SRFLA, educators can help students become more independent learners who are capable of taking charge of their own learning experiences. The study also indicates the importance of fostering intrinsic and extrinsic motivations in students. Educators should strive to create engaging learning experiences that promote students' intrinsic goal orientation, task value, and self-efficacy for learning and performance. This can be achieved by incorporating interesting and relevant content, setting achievable yet challenging goals, and providing timely feedback and support. Furthermore, the study underlines the potential of technology in enhancing science education. As technology continues to advance, educators should stay updated on emerging tools and techniques that can support students' learning processes. By integrating technology into the SRFLA, teachers can create a more dynamic and interactive learning environment that caters to students' diverse needs and preferences.

5.1. Limitation and future studies

The present study, while contributing to our understanding, possesses certain constraints that future investigations should bear in mind. Its focus was exclusively on a single science topic, thereby inhibiting the generalizability of the results to other academic domains. Additionally, the selected sample comprised middle school students from a small city in Turkey, a decision informed by our intent to design specific learning environments and training support for this particular demographic. As such, it may not be appropriate to extrapolate these results to various learning contexts or to students of disparate age groups and cultural backgrounds. Owing to the paucity of studies in this area, future researchers should consider conducting their investigations with diverse student populations, considering varied backgrounds and age groups. In the current study, data collection relied on self-administered scales, a method that may introduce self-report bias. Therefore, researchers should exercise caution when employing Likert-type scales in their work and could consider supplementing their data with qualitative measurement tools to enrich the breadth and depth of their findings. While the current study yielded positive results, it is essential to note that the number of participants was relatively small and the application period only spanned a few weeks. These factors limit the study's efficacy and broader applicability. Thus, future studies involving larger participant groups and longer research durations would be of substantial value, potentially enriching the field with more comprehensive and generalizable findings.

5.2. Conclusions

While the flipped classroom approach is widely recognized as a potent tool for science education (Chen et al., 2022), its impact on SRL remains relatively unexplored. This study endeavored to fill this gap by integrating FL with SRL in the context of middle school education, employing a self-regulated flipped classroom approach, as proposed by Lai and Hwang (2016). The findings suggest that the application of FL fostered more effective science learning when compared to the traditional pre-learning activity. Moreover, students instructed within a self-regulated flipped classroom exhibited greater academic success, more favorable attitudes towards science, higher levels of SRL, and enhanced motivation compared to their counterparts taught via traditional FL. A pivotal insight for science educators stemming from this study is that when students are actively involved in planning their learning process, they tend to demonstrate more effective learning outcomes. To support students' cognitive, metacognitive, affective, and motivational skills, diverse methods of in-class or out-of-class activities for SRFLA – such as setting learning goals and reflective practices – can be implemented.

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