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The flipped classroom, an alternative strategy for teaching genetics in high school

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Abstract With the development of pedagogical innovation, the flipped classroom is one of the most effective, innovative, and student-centered teaching strategies of our time that reduce the limitations of traditional transmission strategies of education. In the flipped classroom, students accessed instructional content and course reading at home via videos, whereas class time was dedicated to interactive learning activities, problem-solving exercises, and discussions guided by the teacher. This approach shifts the typical lecture-to-homework sequence, allowing for more interactive and engaged learning in class. Our study aims to evaluate the impact of the flipped classroom on improving the comprehension of genetics and student performance. To this end, we conducted a descriptive experiment from a quantitative perspective. Two different study groups were formed: a control group following a traditional teaching approach which involved in-class lectures followed by homework assignments, and an experimental group using the flipped classroom strategy. This approach allowed us to compare the impact of the flipped classroom methodology against traditional teaching methods. The study collected pre-test and post-test data to evaluate comprehension and performance improvements. The data from this study were analyzed using descriptive statistics and t tests to compare the results of the control and experimental groups and to draw conclusions based on numerical evidence. The results show that students in the experimental group achieved better posttest scores and developed their cognitive abilities than those in the control group. The difference between the standardized learning gains of the two groups was statistically highly significant. This research demonstrates the positive effects of the flipped classroom on the development of learners' cognitive abilities, a strategy centered on learners' needs, and an appropriate integration of technologies.

Keywords: Performance, flipped classroom, genetics, control and experimental groups, t test, cognitive abilities

1. Introduction

In recent years, the quality of education and learning has become a significant global challenge (Osborn, 2006). Education aims to train young people with skills and know-how to contribute to their country's social and economic development (Schleicher, 2018). In this context, the Moroccan educational system has undergone several reforms to improve its performance and quality. Despite the efforts made by Morocco in pedagogical, didactic, and even financial aspects, numerous reports and studies highlight the concerning situation of the Moroccan educational system (Bedmar, 2014).

According to an international evaluation by the OECD's Programme for International Student Assessment (PISA), which measures the competencies of 15-year-old students in mathematics, reading comprehension, and science, almost no Moroccan student reaches a high level in science, which is level 5 (the OECD average being 7%). These results, indicate that Morocco ranks among the lowest-performing countries in science (OECD, 2022).

To address these challenges, Morocco must make education and teaching a central priority, both for the present and future, because of their crucial and primordial importance (Akrim et al., 2010). As Nelson Mandela once noted, "Education is the most powerful weapon which you can use to change the world." It is essential to explore relevant solutions to transform Moroccan schools into modern institutions focused on science, innovation, and technology, which are fundamental parameters for the progress of any society (Organisation des Nations Unies pour l'éducation, la science et la culture, 2019)

In this context, pedagogical innovation can transform education and successfully transition to an innovative school that meets the continuously evolving social, economic, and technological demands. Like other countries worldwide, Morocco has made significant efforts to make technological innovation a source of growth, creativity, and skill development. This effort began in 2005 with the Ministry of National Education's GENIE program (Generalization of Information and Communication Technologies in Education), which included initiatives such as the "Digital Morocco 2013" plan. This plan aimed to equip schools with multimedia tools and train teachers in their effective use (Nejjari & Bakkali, 2017). Despite ambitious goals, the GENIE program was criticized for its lack of efficiency and effectiveness (Naji, 2020).

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In response, the Ministry of Education has turned to alternative methods, such as creating resources for its official TelmidTICE platform or broadcasting them on national television and radio channels. These ICT generalization programs in the educational sector aim to combat school dropout rates and integrate Morocco into information societies. Thus, pedagogical innovations emphasizing student autonomy and responsibility in the learning process are necessary to develop new skills such as communication, problem-solving, and teamwork via various synchronous and asynchronous communication techniques (UNESCO, 2004).

2. Theoretical Framework

Today, with the profound societal changes driven by technological advancements, many sectors benefit from information and communication technologies (ICTs), such as industry, economy, medicine, etc., including education. Therefore, decision-makers and education leaders are calling for pedagogical innovation through the integration of information and communication technologies (ICTs) in teaching as shown in the Tables 1 and 2 (Nebri, 2016).

Table 1 Flipped classroom (Nebri, 2016).

	School	Home
Teaching	Teacher facilates student collaboration	Teacher shares lectures / videos with students 
Learning	Students work with peers to solve problems 	Students watch videos, read the course

Table 2 Traditional classroom (Nebri, 2016).

	School	Home
Teaching	Teacher instructs and students take notes 	
Learning		Completes assignments at home 

To ensure better learning quality and overcome the difficulties that students face in their learning process, some teachers are adopting innovative strategies in their teaching practices. This pedagogical approach combines multiple teaching methods, primarily based on a socioconstructivist approach, and integrates ICT. This innovation, termed "flipped classroom" (Lakrami et al., 2018), contrasts with traditional transmissive teaching methods. To better understand what a flipped classroom entails and its specific foundations, we compare it with traditional transmissive teaching, as shown in the tables below (Nebri, 2016).

In the case of flipped classrooms, the transmissive part of a lesson occurs "at a distance" before the session via videos, readings, and preparation exercises. Learning in the classroom is then based on group work and interactions with the teacher and peers through activities. According to Lecoq and Lebrun (2016), the flipped classroom is not just about "watching videos before class and doing exercises and applications during class." It represents a profound shift in how students engage with knowledge and the roles played by both students and teachers. Teachers act as facilitators, guiding students through the learning process while allowing them to shape their understanding. This approach involves a "spatiotemporal shift in these various activities."

Another significant distinction is that the traditional approach focuses on lower-level cognitive activities such as knowledge and understanding in the classroom, whereas higher-level cognitive activities such as application, analysis, evaluation, and creation are performed outside the classroom. However, according to Bloom's taxonomy, a flipped classroom engages students in higher-level cognitive skills in class through active and collaborative activities, whereas lower-level cognitive skills are addressed remotely (Ay & Dağhan, 2023).

Many researchers and educators find that flipped classrooms, which integrate ICT, offer an alternative educational approach that fosters digital literacy and critical thinking among students. Many studies have evaluated the impact of flipped classrooms in Canada, France, and especially in the United States (Manon, 2016). A recent study indicated that this practice significantly contributes to improving students' outcomes (Fulton, 2012). In science education, researchers have explored that one of the most challenging areas in science for students in middle school, high school, and even universities is genetics (Lewis & Wood-Robinson, 2000).

On the basis of our previous article "DIFFICULTIES RELATED TO MOLECULAR GENETICS LEARNING AT UNIVERSITY: CHARACTERIZATION AND ANALYSIS OF RESULTS" Retrieved from https://american-jiras.com/soumia-Ref1-ajira250622.pdf and studies conducted by scientific researchers (Knippels et al., 2005). We were able to characterize the difficulties faced by students in favor of genetics (middle school, high school, and university) to understand their origins and causes and to suggest solutions and remedial approaches. These studies reveal that the difficulties encountered by students in favor of genetics are methodological, curricular, cognitive, and linguistic. Among other issues, the teaching of this discipline is characterized by traditional and dogmatic teaching methods that focus on knowledge recall without providing exploitable learning situations to help students reinforce acquired knowledge and build new understandings, thereby failing to give meaning to genetic concepts and scientific phenomena.

As a result, the teaching of genetic content is segmented into multiple chapters according to the official national curriculum, leading to decontextualization, poor structuring, and a lack of a comprehensive scientific culture that integrates all the information and scientific phenomena into a cohesive and meaningful disciplinary field. Adding to these difficulties are real cognitive gaps related to the theme itself, as fundamental concepts of genetics and its biochemical and molecular explanatory aspects, as well as cellular divisions (mitosis and meiosis), are largely ignored by most students. Additionally, the French language poses a significant obstacle, hindering the understanding of scientific concepts.

These difficulties can make learning genetics challenging for students. They may feel frustrated and demotivated and may even struggle to succeed in national exams, competitions, and throughout their university journeys (Wynne et al., 2001).

Through our article, we aimed to innovate the teaching of biological sciences, particularly genetics, and adopted innovative teaching strategies to improve the outcomes of second-year high school students and mitigate the difficulties they may encounter when taking this course at faculties of sciences, medicine, and health institutes. We implemented an innovative strategy known as a flipped classroom. On the basis of a review of the literature and our previous study, "Statistical laws of the inheritance of hereditary traits in diploids" constitutes an interesting chapter in genetics that is frequently studied at school. However, this approach poses challenges for students in comprehension topics such as crossing during meiosis, relationships between phenotypes and genotypes applying Mendelian rules, chromosomal interpretation, the origin of genetic diversity, etc. This is why we chose this topic for study, aiming to help students better grasp this important aspect of genetics. Our study aims to answer the following question: Can adopting the flipped classroom approach enhance the understanding of the statistical laws governing the transmission of hereditary traits in diploids and, consequently, improve student performance in genetics? In other words, what impact could the flipped classroom have on the outcomes of high school students?

We formulate two fundamental hypotheses to answer this question: H0 and H1.

• Hypothesis 0: A flipped classroom does not improve learners' outcomes.

• Hypothesis 1: Flipped classrooms can mitigate learning difficulties related to genetic concepts and help students better grasp them.

We will then examine the results of applying this approach to assess its potential impact on enhancing education in the life sciences and earth sciences, particularly in the genetics field.

3. Materials and methods

Indeed, traditional teaching practices and activities outlined in the curriculum for teaching this topic in textbooks do not achieve the objectives set by official recommendations.

To assess the effectiveness of flipped classrooms as an alternative solution to address the numerous challenges related to teaching Mendelian genetics in high school, we chose an experimental pretest (score before the intervention) and posttest (score after the intervention) methodology as a quantitative approach. This approach was selected because it allows for random assignment of control and experimental groups without disrupting classroom organization (Cohen et al., 2007). It is a quantitative method of descriptive and correlational nature and is considered suitable for comparing the average scores of participating student groups and measuring the degree of improvement in outcomes following the intervention.

3.1. Sampling:

Our experimental study involved a sample of 64 students in the 2nd year of the baccalaureate, with the physical sciences option (PC), and 57 students with the life and earth sciences option (LES), continuing their studies at a qualifying high school in the Marrakech-Safi region, Morocco. Table 3 summarizes the characteristics of the participants in the study groups.

Table 3 Distribution of Students in the Control and Experimental Groups.

Option	Total number of learners	Groups	Numbers of learners	Females	Males
		Control group	32	18	14
PC	64	Experimental group	32	21	11
		Control group	29	16	13
LES	58	Experimental group	29	17	12

Table 3 shows an approximately equal sample size distribution between groups and options. To comply with the requirements for implementing a flipped classroom, we divided each two classes into two groups according to the rules for implementing this practice. Two groups were defined: the control group and the experimental group. In the control group, we used a traditional method, whereas in the experimental group, we employed an innovative strategy based on flipped learning.

3.2. Data analysis

Data analysis was conducted via IBM SPSS Statistics 20. For basic statistics such as the mean (M) and standard deviation (SD), we employed descriptive statistics and Student's t_test in SPSS to compare the means of the two groups representing independent samples. To assess the effectiveness of the flipped classroom method compared with traditional methods, we measured each student's learning level by calculating the learning gain (gi) for cognitive ability. The reliability of the tests was checked via a method called internal consistency, measured by Cronbach's alpha coefficient, yielding values of 0.775 for Physics-Chemistry and 0.819 for Life Sciences. Generally, a high Cronbach's alpha value (above 0.70) indicates good internal reliability (Nunnally, 1978).

3.3. Description of the framework:

Before implementing a flipped classroom for the genetics course, we obtained permission from the local authorities to conduct the study at the school. All the participants were informed that their participation was voluntary and that the data collected would be kept strictly confidential and anonymous. Next, we presented the students with a short video clearly explaining the concept of flipped classrooms, emphasizing the need for tools and proficiency in new information and communication technologies. To ensure the smooth implementation of the experiment, we facilitated access to multimedia rooms at high school for students who did not have computers at home or provided them with handouts. In terms of spatial organization, dedicated classrooms were allocated for students to work in groups. This collaborative approach encourages the sharing of ideas between students, develops critical thinking, and improves scientific communication. To deliver content to students, we utilized the educational platform Padlet, which is accessible at https://padlet.com/soumiabaroud1995/padlet-qjozqldlfogn.

The choice of this platform is justified by its speed and accessibility to PCs, mobile phones, or tablets. This educational platform allows us to upload content in various formats (videos, animations, internet research, interactive activities, excerpts from books, websites, etc.). Only authorized students with access can view the offered courses. As part of this experiment, our preparatory work before the class was significant, as we were responsible for preparing activities, course materials, and teaching-learning situations related to the previously mentioned unit. To achieve this goal, on the basis of official pedagogical instructions, studied three national manuals and frameworks and examined the results of diagnostic evaluations. We also selected or created video capsules and animations to explain the course content.

A pretest was conducted and distributed to ensure equivalence of knowledge between the two groups (control and experimental). After completing the assigned tasks, the students in both groups were asked to respond to posttest questions to compare their answers and analyze the results.

4. Results

4.1. Pretest Results

As mentioned earlier, the objective of this research is to evaluate the effect of flipped classrooms on student performance in genetics and identify the cognitive abilities of students who benefit most from this innovative approach. To verify the equivalence of the control and experimental groups, we used a t test to compare the pretest and posttest results according to the cognitive abilities of both the PC and SVT options.

Both tests and the assessment grid were prepared and subsequently approved by experts in science education: trainers of future teachers in Life Sciences at the Regional Center for Education and Training Professions in Marrakech-Safi, certified professors in Life Sciences at ENS, and university professors. On the basis of the feedback and suggestions from these professors, both tests were revised to ensure the validity of the answer keys. The final tests included exercises distributed across four levels of cognitive ability: knowledge, comprehension, analysis and synthesis, and application.

Table 4 presents the results of descriptive statistics in terms of mean scores and standard deviations obtained by students in the pretest for both the SVT and PC options.

Table 4 Pretest scores of the students in the control and experimental groups.

Option	Group	N	Mean
LES	Control	29	7.61
	Experimental	29	7.86
PC	Control	32	8.64
	Experimental	32	7.84

To determine if the difference between the means of the two groups was statistically significant and to reject the null hypothesis (H0), which indicates that no significant difference existed between the two groups during the pretest, we used

Student's t_test to compare the means of the two independent samples. Table 5 provides the descriptive statistics in terms of the mean scores and standard deviations obtained by the students from both groups in the pretest.

Table 5 T test results for average pre and posttest scores for both LES and PC options.

	Levene's test for equality of variances.		Test t for equality of means		The confidence interval of the difference at 95%	
Pré-test	F	p value	t	p value	Lower	Higher
LES	2.266	0.138	0.303	0.763	-1.40283	1.90283
PC	1.422	0.238	0.364	0.177	-0.7305	1.9643

According to Table 5, the analyses show that for life science students and earth science students, the variances appear to be homogeneous (F = 2.266), and the p-value is 0.763, which is higher than the chosen alpha level. A similar situation is observed for physical science students, where the variances are also homogeneous (F = 1.422) and the p-value is higher than the chosen alpha level. Therefore, we cannot reject the null hypothesis H0, suggesting that there is no significant difference between the groups tested in terms of conceptual understanding. In other words, students from both groups show similar levels of comprehension, which are characterized as weak and mediocre, indicating a superficial acquisition of concepts. This situation may be attributed to a traditional teaching method focused on knowledge recall and memorization.

According to the analysis of the results presented in the tables 6 and 7, the mean scores of the students in both groups on the pretest were similar. Additionally, low performance was recorded in Bloom's cognitive skills (knowledge, comprehension, application, analysis, and synthesis); these skills were considered independent variables. We concluded that the results revealed low and mediocre levels of scientific reasoning among the students in both groups. This finding shows that both groups, regardless of their options (physical sciences or life and earth sciences), had a similar comprehension of the objectives before the start of the experiment.

Table 6 T test Results for the Average Pretest Scores According to Cognitive Abilities for LES.

Statistics of the groups							
LES	Group	N	Mean	Standard deviation	t	ddl	P value
PreTest	Control	29	7.61	2.77	0.303	56	0.763
	Expérimental	29	7.86	3.46			
Knowledge	Control	29	2.76	1.02	-0.268	56	0.790
	Expérimental	29	2.68	1.17			
Comprehension	Control	29	2.68	1.11	-0.163	56	0.871
	Expérimental	29	2.63	1.29			
Analysis	Control	29	1.39	0.76	1.209	56	0.232
	Expérimental	29	1.54	0.87			
Application	Control	29	0.77	0.74	0.671	56	0.505
	Expérimental	29	1.00	0.66			

Table 7 T test results for the average pretest scores according to the cognitive ability of the PC.

Statistics of the groups							
PC	Group	N	Mean	Standard deviation	t	ddl	P value
Pretest	Control	32	8.64	2.50	1.364	62	0.177
	Experimental	32	7.84	2.15			
Knowledge	Control	32	3.15	1.02	0.377	62	0.707
	Experimental	32	3.25	0.95			
Comprehension	Control	32	2.93	1.24	1.587	62	0.118
	Experimental	32	2.50	0.94			
Analysis	Control	32	1.04	0.88	1.456	62	0.150
	Experimental	32	1.06	0.71			
Application	Control	32	0.81	0.83	0.078	62	0.930
	Experimental	32	1.10	0.80			

4.2. Posttest Results

Table 8 presents the results of descriptive statistics in terms of mean scores obtainedby students in the posttest for both the SVT and PC options.

Table 8 Posttest scores of students in the control and experimental groups.

Options	Group	N	Mean
LES	Control	29	8.63
	Experimental	29	13.11
PC	Control	32	9.77
	Experimental	32	14.88

The results of the posttest scores of the students in the life and earth sciences options show that the mean score of the students in the experimental group is 13.11 (standard deviation =2.88), whereas that of the students in the control group is 8.63 (standard deviation =2.29), with a difference of 4.47 between the two means. In the physical sciences, the mean of the students in the experimental group was 14.88 (standard deviation = 1.62), whereas that of the students in the control group was 9.77 (standard deviation = 1.99), with a difference of 5.10 between the two means as seen in Table 8.

To determine if the difference is significant and to reject the null hypothesis (H0) that the flipped classroom, as a teaching strategy, did not affect student results, we used Student's t test. This test compares the means of two independent samples following a normal distribution. The results of this comparison are presented in Table 9:

Table 9 T-test Results for the Average Scores in the Pretest According to Cognitive Abilities for Both the PC and LES.

Option	Group	Mean	N	t	DDL	P value	The confidence interval of the difference at 95%	
							Lower	Higher
LES	Control	8.63	29	6.533	56	0.000	3.10	5.84
	Experimental	13.11	29					
PC	Control	9.77	32	-11.202	62	0.000	-6.01	-4.19
	Experimental	14.88	32					

According to Table 9 this table, the p values for both groups are equal to 0.000, a value below the chosen alpha level ($p<0.05$). A p value of 0.00 indicates that if the p value is less than 0.05, we reject the null hypothesis that there is no difference between the means. Moreover, the lower and upper bounds of the confidence intervals are all of the same sign, meaning that these intervals do not include the value 0. This implies that the null hypothesis, which asserts the equality of means, must be rejected.

We can deduce that the difference in the mean scores obtained by the students in the post and pretest is statistically significant. This finding indicates that the performance e of the experimental group significantly exceeded that of the control group for both options, PC and SVT. Therefore, we accept the alternative hypothesis H1. We conclude that the new strategy of the flipped classroom in the teaching and learning of life and earth sciences, particularly genetics, has a significant positive impact that exceeds that of the traditional approach, which is limited to lectures and exercises.

4.3. Impact of the Flipped Classroom on Student Performance

To evaluate students' performance, Bloom classified educational objectives into specific categories (knowledge, comprehension, analysis/synthesis and application). On the basis of Bloom's cognitive abilities, we analyzed the results to determine the point at which the flipped classroom can improve our students' abilities. The results below present the performance of the four abilities (knowledge, comprehension, analysis, and application) in the posttest, as well as the calculation of learning gain to evaluate the impact of the flipped classroom on the evolution of these abilities for students in both the SVT and PC options (Tables 10 and 11).

Progress in conceptual learning was assessed by comparing test results before and after the intervention. To avoid ceiling or floor effects, where scores could be falsely high or low, conceptual improvements were normalized and compared. Each participant's conceptual gain was calculated via the normalized gain formula used by Hake (1998):

$$g = (\%posttest – \%pretest)/(max\ T – \%pretest) \qquad (1)$$

This measure gives the ratio of the raw conceptual gain (difference between posttest and pretest scores) to the maximum possible gain. For example, an average normalized gain of 0.316 means that, on average, students achieved approximately 31.6% of the maximum possible gain after the intervention. This provides an idea of the relative effectiveness of the intervention compared with the maximum possible improvement potential.

Table 10 T test Results for the Average Posttest Scores According to Cognitive Abilities for LES.

Statistics of the groups							
LES	Group	N	Mean	Sd	T	DDL	P value
Posttest	Experimental	29	13.11	2.88	6.533	56	0.000
	Control	29	8.63	2.29			
Knowledge	Experimental	29	2.59	1.04	4.950	56	0.000
	Control	29	1.46	0.63			
Comprehension	Experimental	29	3.65	0.94	5.451	56	0.000
	Control	29	2.15	0.89			
Analysis	Experimental	29	3.06	0.97	2.627	56	0.000
	Control	29	1.86	0.69			
Application	Experimental	29	3.91	1.16	6.195	56	0.011
	Control	29	3.03	1.37			

Table 11 T test results for the average pretest scores according to the cognitive ability of the PC.

Statistics of the groups							
PC	Group	N	Mean	Sd	T	DDL	P value
Posttest	Experimental	32	14.88	1.62	-11.202	62	0.000
	Control	32	9.77	1.99			
Knowledge	Experimental	32	3.56	0.91	-3.501	62	0.001
	Control	32	2.83	0.74			
Comprehension	Experimental	32	3.29	0.99	-4.438	62	0.000
	Control	32	2.32	0.72			
Analysis	Experimental	32	4.53	0.63	-7.757	62	0.000
	Control	32	2.50	1.33			
Application	Experimental	32	3.59	0.78	-7.796	62	0.000
	Control	32	2.10	0.73			

On the basis of the results of the learning gain calculation for each cognitive ability, a significant difference was observed between the competence levels of the experimental groups, which obtained scores ranging from 3.56/5 to 4.53/5, significantly higher than those of the control groups, which did not exceed 2.5/5, as seen in Tables 10 and 11. In other words, the students in the experimental groups performed particularly well on questions related to analysis/synthesis and application abilities. It was also observed that the students had very good comprehension and assimilation of genetic concepts after taking the flipped classroom. In contrast, the control groups were limited to knowledge and partial comprehension, without mastering the abilities of analysis and application.

In other words, the experimental students performed better than the control students did. This can be explained by the fact that the control groups did not benefit from the intervention that the experimental group received. In the flipped classroom, students are more active in the course and assume an active part in their knowledge building. The flipped classroom is an effective and essential strategy for teaching life and earth sciences and is characterized by a heavy curriculum. This teaching strategy reduces the content load and allows more class time to be devoted to developing students' higher-level cognitive abilities, thus preparing them to become active citizens capable of thinking critically and solving problems.

On the basis of the results presented in Tables 10 and 11, we observed an improvement in several cognitive abilities through teaching via the new flipped classroom strategy. To precisely identify the performance developed by this strategy, we calculated and interpreted the conceptual gain (N-Gain) for each experimental and control group in the two options studied using Table 12 by Hake (2002).

Table 12 Interpretation of the N-gain score.

N-gain score	Criteria
≤N-gain < 0.3	Low
0.3≤N-gain < 0.7	Medium
N-gain > 0.7	High

We subsequently conducted a t test to determine the statistical significance of differences between the N- gains of the control and experimental groups.

Compared with the control group, the students who received the flipped classroom instruction experienced significant improvements in their cognitive abilities, with a learning gain of 0.76 for the PC group and 0.56 for the LES group, which did not exceed 0.11, as seen in Figure 1.

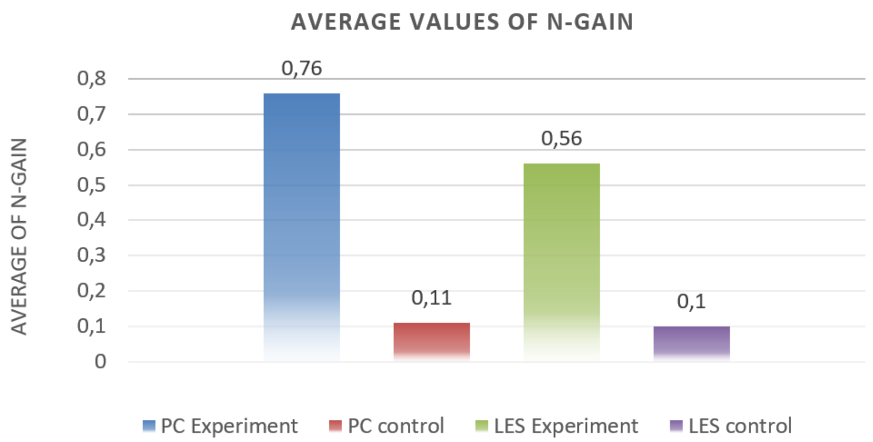

Figure 1 Average N gain values of the experimental and control groups for both Options.

These results were confirmed by an independent analysis via a sample t test, which demonstrated that the flipped classroom strategy has a positive effect on improving students' PC and LES abilities, particularly in genetics, as shown in Table 13.

Table 13 N-gain results of the experimental and control groups according to cognitive ability.

Option	Abilities	Groups	Pretest	Posttest	N-Gain	C	T	p value
	Knowledge	GC	2,76	1,46	-0,58	Low	4,950	0.000
LES		GE	2,68	2,59	-0.03	Low		
	Comprehension	GC	2,69	1,86	-0.35	Low	5,451	0.000
		GE	2,63	3,06	0.18	Low		
		GC	1,39	3,03	0,45	Medium	2,627	0.000
	Analysis	GE	1,54	3,91	0,78	High		
	Application	GC	0,77	2,15	0,32	Medium	6,195	0.000
		GE	1,00	3,65	0,66	Medium		
	Knowledge	GC	3,15	2,83	-0,17	Low	3,501	0.000
Pc		GE	3,25	3,56	0,17	Low		
	Comprehension	GC	2,93	2,32	-0.29	Low	4,438	0.000
		GE	2,50	3,29	0,31	Medium		
		GC	1,04	2,10	0.26	Low	7,757	0.000
	Analysis	GE	1,06	3,59	0.64	Medium		
	Application	GC	0.81	2,50	0,40	Medium	7,796	0.000
		GE	1,10	4,53	0,87	High		

5. Discussion

According to the pretest results, students in both the PC and SVT groups had difficulty understanding key concepts in genetics, especially scientific reasoning questions. This confirms that the traditional approach does not facilitate the comprehension of the concepts studied. Such an approach only develops the ability to recall knowledge. However, many authors (Donnay & Romainville, 1996; Houssaye, 2014; Loila & Tardif, 2001) assert that students who do not make a mental effort are limited to passively receiving and memorizing roles in lessons.

In the flipped classroom, the experimental groups watched the videos, discussed and exchanged views, and explained the concepts to students who didn't understand them. We ensured that they had a solid grasp of genetic concepts before solving the problem. In this context, many studies have demonstrated its benefits, such as a high level of student engagement and improved participation in activities (Bergmann & Sams, 2014). It also fosters students' autonomy by adapting learning to their own pace and needs (Kharchi, 2017). It strengthens relationships with peers and improves interaction in the educational process (Kwon & Woo, 2017). According to Taurisson & Herviou (2015), students have a better ability to solve problems during their learning process.

In contrast, the students in the control group were limited to listening to the lecture, doing application exercises, and directly tackling problem-solving without engaging in situational activities. This approach prevented them from mastering the studied concepts, solving the problems effectively, and consequently achieving good results in the posttest. The scores of the two tests indicate a significant difference between the control and experimental groups, which could be explained by the influence of the flipped classroom on improving genetics learning. The control group students were unable to correctly answer the posttest questions, particularly the scientific reasoning questions, which demonstrates their inability to transfer the acquired knowledge to solve problems in different situations. It is possible that the poor performance of the control group was due to their passive role in constructing their knowledge. Our results are consistent with those of the study conducted by Freeman et al. (2014) compared the performance of primary and secondary level students who were taught by the active methods in disciplines such as science, technology, engineering and mathematics (STEM) to that of traditional class students, their analyses revealed a mean score of 6% higher in students from active learning courses than those from passive learning courses (traditional). There was also a lack of cognitive conflict and mutual support between students, the absence has caused a decrease in the richness of discussions and reduced stimulating exchanges. Without real critical discussion and greater cooperation, students had fewer opportunities to express their ideas and benefit from the exchange of opinions, which may have restricted their learning. To remedy this, it would be useful to encourage more dynamic and active debates and to reinforce mutual support to enhance interaction and improve the quality of learning (Roseth et al., 2008).

We concluded that this preliminary experiment requires significant effort, adaptation, and maturation to be effective. Indeed, internal factors such as student motivation and external factors such as technical issues (availability of the multimedia room and insufficient workstations, Internet connections, etc.) can hinder only the success of these experiences.

The results of this experiment revealed that the use of this approach has a substantial positive effect on students' learning, such as increased retention of information, improved critical thinking skills, greater engagement and motivation in the classroom, as well as higher academic performance and higher levels of satisfaction with the learning experience, as revealed by many studies (Forsey et al., 2013; Fulton, 2012; Mason et al., 2013; McLaughlin et al., 2014 ; Pierce, 2013 ; Tune et al., 2013; Wilson, 2013; Ben Mesouad et al., 2023; δ Nouri, 2016).

However, its implementation faces several problems related to the lack of technical tools among students and curricular constraints (Guilbault δ Viau-Guay, 2017). According to the students, the flipped classroom stimulates their curiosity to learn, ask questions, and propose study strategies within groups. However, some students are not satisfied with this approach, primarily for economic and technical reasons (Enfield, 2013). Additionally, many teachers expressed resistance toward these innovative teaching strategies, reflecting a lack of awareness of the importance of pedagogical innovation in education. The same results were reported previously by Stone (2012).

6. Conclusion

On the basis of the literature mentioned above regarding Mendelian genetics, this study revealed positive results that partially support the findings of previous studies. Moreover, the results are significant for studying the effectiveness of the flipped classroom approach for the conceptual understanding of Mendelian genetics. With these results, we believe that the flipped classroom approach could gradually change how teachers and students perceive education. As confirmed by the results of the questionnaire and interview analysis in our previous study, as well as the conclusions of this study, the majority of the students in the control class had misconceptions about the scientific concepts in genetics of the study, which were the root cause of the learning difficulties. The student's inability to master the mechanism of Mendelian genetics reveals the inadequate articulation of the scientific concepts of genetics, these difficulties are the consequences of traditional teaching methods with transmissive pedagogy. To overcome the difficulties of teaching and learning genetics difficulties, we propose the flipped classroom methodology as an alternative strategy and a solution to these problems and obstacles. To do this, we evaluated the impact of our study strategy on students in an experimental group by comparing it with that of a control group. The results of this experiment revealed that the practice of flipped classrooms can significantly impacts improve students' learning. According to the students. This strategy study approach can facilitate learning, stimulate student motivation, develop their scientific reasoning abilities, and promote students' autonomy in the construction of their knowledge. However, challenges such as limited access to technical tools and program constraints may affect the effectiveness of this strategy.

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Ethical considerations

We obtained permission from the local authorities to conduct the study at the school. All the participants were informed that their participation was voluntary and that the data collected would be kept strictly confidential and anonymous.

Conflict of Interest

The authors declare no conflicts of interest.

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