Effectiveness of the Flipped Classroom in the Teaching of Mathematics in an Online Environment: Identification of Factors Affecting the Learning Process

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Abstract
The purpose of this study was to carry out an analysis of the effectiveness of the Flipped Classroom methodology for teaching mathematics—specifically geometry, in an online environment. Specifically, we measured: (1) the academic achievement of students who were taught based on this method; and (2) the perceptions of satisfaction with this methodology and with the virtual sessions attended through digital resources. In order to gather the data a pre-experimental and ex-post-facto design was used with a sample of 113 secondary education students. Regarding academic performance, positive and significant differences were found between the pre-test and the post-test. In addition, different significant variables were found that affected the academic performance of the students, such as having previously failed the subject of mathematics, the perception of the students about their effort in learning mathematics or the educational level of the parents. In respect of the students' perceptions, the results showed that they were generally happy with the use of the Flipped Classroom methodology, bearing in mind that the environmental context in which the educational process takes place affects the students' perceptions. However, slightly negative perceptions were also found in respect of virtual sessions that made use of digital resources. These findings were significantly affected by the frequency with which resources and electronic devices were deployed. These results would support the integration of this methodology into the teaching of mathematics, where the use of digital resources to study geometry in particular helps to improve the different competences and skills of the students.

Keywords: students, Flipped Classroom, educational innovation; research methods, online education, academic achievement

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The recent pandemic caused by SARS-CoV-2 presented the educational community with an unprecedented challenge: how to acquire the skills to teach online (Bautista et al., 2022). UNESCO (2020) reported that 1.6 billion students from more than 190 countries made the transition from traditional learning methods to virtual ones. This had a major impact on the pedagogical and social aspects of teaching with psychological aspects also coming into play (López-Noguero et al., 2021). This new challenge "has shaken up teachers at all levels and at the same time inspired them to find solutions to problems they have not encountered before" (Flores & Swennen, 2020, p. 456). Technology now must be viewed as a key tool for education in the 21st century. This particularly applies to the study of mathematics (McCulloch et al., 2021), with a particular relevance for geometry, the area of interest in this study.

The shift to online teaching has given a big impetus to the use of information and communication technology (ICT) in the area of mathematics. The pedagogical vision (Weinhandl & Lavicza, 2021) states that the physical presence of an educator is not required, and neither is that of a classroom (Camacho et al., 2020). In other words, the space-time barriers have been reduced in virtual teaching thanks to the teaching strategies carried out by the teachers (Weinhandl et al., 2020). This advance has favored the use of digital resources both in a synchronous and asynchronous way (Schallert & Weinhandl, 2019), where the student has the role of protagonist with a more active role. In this online context, Hossein-Mohand et al. (2021) states that learning mathematics could be much more significant and enriching for the students themselves. Furthermore, in the context of this study, the use of ICT will allow not only the development of students' geometric thinking (Zaranis & Synodi, 2017), but also the visualization of geometric figures (Dockendorff & Solar, 2018), through augmented reality for example (Arvanitaki & Zaranis, 2020).

To frame the study of mathematics within a more realistic context, the use of active methodologies helps students to actively construct their own learning process (Azevedo & Maltempi, 2020). One example of this is the Flipped Classroom (FC) (Campillo-Ferrer & Miralles-Martínez, 2021). Şenel et al. (2020, p. 77) define FC as "to transform the traditional instructional method to a novel approach with the use of instructor-developed videos and interactive activities such as problem-based and collaborative activities." According to Tucker (2012), the FC procedure is as follows: at the beginning of the application of this methodology, students asynchronously access and study the theoretical content of the course (through different digital resources such as documents, videos, or multimedia presentations). This action is carried out before the students begin the synchronous sessions in which they will participate and interact with the teacher and classmates in solving problems and doubts (Galindo & Bezanilla, 2019). With these actions, more active, collaborative, and significant learning for the student would be achieved. In short, as Giménez & Porlán (2017) and Herrera & Prendes (2019) state, the FC model is to do at home what is traditionally done in the classroom, and what is commonly done at home as homework is done in the classroom. In our case for this study, FC was implemented through virtual learning platforms and videoconference platforms, respectively.

This methodology offers a range of benefits, from helping students to learn autonomously (Zainuddin & Perera, 2019), and improving academic results (Bulut & Kocoglu, 2020; Cronhjort et al., 2018), to encouraging the students to interact with one another (Son, 2016; Xiao et al., 2021) and to work on intrinsic aspects such as emotions, motivations, and interests (Kim et al., 2014). However, as pointed out by Mengual-Andres et al. (2020), for the educational process to succeed through FC an ideal working environment is required to optimize the visualization of content in digital format. The literature has shown that in the area of mathematical knowledge, the male gender is linked with higher skills and qualifications compared to the female gender (Abín et al., 2020; Gomes et al., 2020). To address this, it is necessary to focus on teaching mathematics irrespective of gender stereotypes and to give the students a more practical, motivational angle (Husein et al., 2018; Maass et al., 2019). The use of FC methodology can provide a good alternative to support this objective.

As a key factor—and in common with other methods—the FC method primarily aims to reorganize and optimize the use of time in the teaching-learning process (Balan et al., 2015; González et al., 2016). As the usual class structure is flipped around, students can access pre-classes or videos (Ríos & Romero, 2022) that contribute greatly to the fundamental knowledge that turns students into active participants in classroom discussions (Fung, 2020). Teachers adjust to the pace and interests of their students. This process is supported (Guillén et al., 2020; Limniou et al., 2018) by the presence, guidance, and expertise of the teacher, who spends time enhancing and facilitating other processes of knowledge acquisition and practice, applying concepts and creatively engaging with content, answering questions, and solving problems (Jeong et al., 2021). Applied to the area of mathematics, different studies show how FC favors mathematical problem-solving, meaningful learning, motivation, and academic performance (Adams & Dove, 2016; Bhagat et al., 2016; Clark, 2015; Kirvan et al., 2015; Lo et al., 2018).

In short, the use of active methodologies such as FC would be a good option, as it presents a multitude of benefits to train students academically, where the use of digital resources will allow them to continue with online education COVID during the pandemic. However, no studies exist that connect the application of this methodology in the classroom with the use of ICT in online scenarios, which is the main objective of this study. Thus, the objectives of this study are:

(1) To analyze students' academic performance in the subject of mathematics (knowledge area, geometry) when using the FC methodology in a distance learning educational scenario.

(2) To find out students' perceptions of the use of the FC methodology, as well as the use of ICT resources in virtual sessions.

(3) To identify predictors that affect both students' academic performance and their perceptions about FC and use of virtual sessions.

Theoretical Framework

The Effect of FC on Student Learning and Satisfaction

On the one hand, research has shown the positive impact on the academic performance of students in secondary education (Guillen-Gamez et al., 2019). There is abundant literature on this topic up to the point that there are several meta-analyses that summarize this information. The study by Strelan et al. (2020) showed a moderate and positive effect of FC between control and experimental groups (n = 21; Hedges' g = 0.64). In the same context, Wagner et al. (2020) carried out an analysis on the effectiveness of this methodology through "post-test only", "pre-test-post-test (time)" and "pre-test-post-test with control group (treatment)" designs, finding a moderate effect size (n = 25; Cohen's d = 0.42). Similar results were also reported by Galindo-Domínguez (2021). Against this backdrop, we agree that at the very least, the use of this FC methodology "yielded a neutral or positive impact on student achievement when compared to traditional classroom" (Lo & Hew, 2017, p. 1). Therefore, it is essential that there is a good learning of mathematics by the students so that they do not repeat the academic year. In this context, Alexander & Maeda (2015) state that the use of the FC methodology can be ideal for achieving both positive learning and academic performance in students.

On the other hand, other studies have focused on analyzing students' perceptions of FC. Gómez et al. (2015) used a post-test design in a control and experimental group, with a sample of 29 secondary school students from Seville (Spain). The results showed no differences as to satisfaction, although they did show more positive differences in respect of the pace of learning and effort towards mathematics for the experimental group. Similar results were found by both Stratton et al. (2020) and Kazu & Kurtoglu (2020), also finding that gender is not a significant variable. In the same context, Yang (2017) used a qualitative design with interviews with students (n = 3) at the secondary school stage. Not only did this show that students had a more positive perception of themselves, but they also developed greater self-management and motivational skills, although the latter did not present in all students. As to motivational skills, Young (2015) found that students develop a negative attitude towards mathematics after using this methodology, which is similar to those of Lape et al. (2014), who emphasized students' lack of motivation due to not being taught the subject in face-to-face classes. An effect such as this may pose a general difficulty in the implementation of the flipped classroom in mathematics, where carrying out this methodology in virtual sessions is likely to yield better results.

Finally, many authors have tried to analyze predictors that affect students' academic performance or perceptions of FC. Gender is one of the best-known predictors, with more positive ratings for females (Chiquito et al., 2020; Gross et al., 2015), although other studies reported opposite results (Guillen-Gamez et al., 2019). Others did not find any significant differences (Cho et al., 2021; Kadry & El Hami, 2014; Onojah et al., 2019). Regarding perceptions, disparate results have been found in the literature, finding more favorable results in the male gender (Aljaraideh, 2019) but, conversely, also in the female gender (Colomo-Magaña et al., 2020).

The Effect of Digital Resources on Student Learning

As to online learning, the use of digital resources is an essential tool. Nevertheless, Adarkwah (2021) states that "there is an uneven spread of access to ICT among different populations, households, and spaces because network coverage varies locally," so differences occur in terms of academic performance or student satisfaction among those using digital tablets versus those using laptops, with the latter ranking higher (Liberatore & Wagner, 2021).

Another significant factor studied in the literature has been the attitude towards ICT (Romero et al., 2020). Specifically, Peytcheva-Forsyth et al. (2018) have analyzed the relationship between this type of attitude and the learning of mathematics, finding more favorable attitudes for the female gender. Moreover, the literature confirms that there is a strong relationship between attitudes towards technology and its use in educational contexts (Hu et al., 2018). This leads to better student skills, including digital skills (Hernández-Martín et al., 2021). If we focus on the area of mathematics, the application of digital resources can have a positive impact on the academic performance of students (Gómez et al., 2020; Sharp & Hamil, 2018). So does the use of mobile applications (Kristianti et al., 2017), which increase both the motivation as well as the performance of students. Thus, the incorporation of technology enhances the motivation for learning mathematics, which is linked to a greater willingness to learn and overall, a better achievement in mathematics (Gilar-Corbi et al., 2019; Hammoudi, 2019; Lipnevich et al., 2016).

Method

Design and Participants

To achieve the objectives of this study, a quasi-experimental design was used where one of the main characteristics of this type of design is that the participants are not assigned according to random criteria (Cook, 2015). With this type of design, both the academic performance of the students and their perceptions of the FC methodology were analyzed. This design was carried out with a three-week treatment through virtual sessions. Specifically, we conducted the experiment with four groups in the fourth year of secondary education, previously assigned at the beginning of the stage. For data collection, a non-probabilistic purposive sample was used, with a total of 113 students in the fourth year of secondary eEducation, from Malaga (Spain), during the 2020–2021 academic year. The distribution of the groups was as follows: group A (24.8%), group B (25.7%), group C (25.7%), and group D (23.9%). In terms of gender, 65.30% were female, while 34.70% were male. The average age of the students was 15.

Instrument

In order to achieve the objectives of the study, two types of instruments were used. On the one hand, several tests were employed to assess the academic performance of the students on one of the didactic units of the mathematics subjects: geometry. These tests were provided by the textbook publisher (SM) and are based on a 10-point scale. And, on the other hand, we used a questionnaire to ascertain the students' perceptions of the FC methodology in virtual sessions, developed by the authors themselves and consisting of two dimensions. The first dimension (DIM-FC) focused on the students' benefits from and satisfaction with the FC methodology used by the teacher, with a total of nine items. The second dimension (DIM-VIRTUAL) was based on student perceptions of the virtual sessions for teaching the practical and theoretical contents of the subject, comprising a total of 12 items. A seven-point Likert scale was used to measure student perceptions, where a value of 1 was allocated to the variable "strongly disagree" and a value of 7 to the variable "strongly agree."

The psychometric properties of the questionnaire were tested through Cronbach's alpha reliability and construct validity with exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). SPSS V.22. AMOS V.22 were used as statistical software. The principal components method with oblimin rotation was used for the PCA. The Kaiser-Meyer measure of sampling adequacy (KMO = 0.9337) as well as Barlett's test of sphericity (χ^2 = 1090.659; gl = 66; sig. = 0.001) showed the dimensionality of the instrument. The model revealed the presence of the two dimensions explaining 73.78% of the true variance in the instrument scores (DIM-FC, 62.10%; DIM-VIRTUAL, 11.58%). As recommended by Henson & Roberts (2006), items that are weighted at less than 0.3 are eliminated as they correlate on different scales. The final version consisted of 12 items. The maximum likelihood method was selected for the CFA, whilst the satisfaction thresholds recommended by Hu & Bentler (1999) were taken into consideration. The first version of the model did not fit with the expectation of the authors, so we refined the items of the tool and eliminated those items that had large covariances with other items outside their own dimension. The second version proved a satisfactory fit with a total of 10 items. Table 1 shows the indices analyzed together with their respective coefficients, while Table 2 shows the questionnaire. In addition, Mardia's coefficient (r.c.) states multivariate normality by finding values between 3 and 70 (Byrne, 2010). This amounted to 10.756 in our model.

Table 1
Psychometric Properties of the Instrument

Coefficients	Model coefficients	Hu & Bentler recommendations
CMIN/DF	1.381	< 3
GFI	.922	> 0.7
NFI	.938	> 0.7
PNFI	.709	> 0.7
IFI	.982	> 0.9
TLI	.976	> 0.9
RMESEA	.058	< 0.07

Table 2
Instrument Items

DIM-Flipped Classroom:
- …is a motivating strategy for learning the subject
- …favours the resolution of doubts about the content of the subject
- …offers me more opportunities to collaborate with my classmates
- …makes it easier for me to understand the content of the subject
- …allows me to develop skills that will be of value in my learning

DIM-Virtual Sessions:
- …improves interactivity with teachers and classmates
- …helps to understand information more clearly
- …encourages my concentration on the teacher's explanation
- …increases the number of digital resources to complement my training
- …improves organization and use of time

Data analysis techniques

The analysis of the results required the following procedures:

- To measure the academic performance of the students, a mixed repeated measures ANOVA was used. The dependent variable (academic performance) was used in the intra-group factor. The study was carried out at three points in time: at the end of the first week of work with the Flipped Classroom methodology through virtual sessions (post-test 1), at the end of the second week (post-test 2) and at the end of the third and final week (post-test 3). As a between-groups factor, the nominal polytomous variable group (group A, B, C, and D) was used. In addition, the assumptions for this test were checked for compliance with Box's M, sphericity of variance (Mauchly), and Levene's test.
- To measure how the students perceived the FC through virtual sessions, we applied both the Wilcoxon and Man-Whitney tests, due to the absence of the assumption of data normality ($p < .05$). Data collection was carried out a couple of days after the start of the project, to give the students time to interact with the digital resources and evaluate their use.
- To identify significant predictors, different statistical tests were used, depending on the design of each variable. Each type of statistical test is described in its corresponding analysis in the results section. This analysis was performed on the scores of the last questionnaire (post-test).

Procedure

The subject of mathematics, specifically a didactic unit (geometry) was taught online through digital resources, using the FC methodology. This online learning was carried out from the homes of all the agents involved in the educational process due to the confinement and the COVID-19 pandemic. For this reason, the entire process of the FC methodology, both asynchronous and synchronous, was implemented online from home. Before the virtual sessions in an asynchronous way, students were provided with videos and digital resources on the theoretical content of the subject of geometry through the Moodle platform. These materials were developed both by the teacher who taught the four groups of students and by one of the researchers in this study, an expert in educational technology as well as a mathematics graduate. During the virtual sessions in a synchronous way, half of them were focused on guidance and resolution of doubts, while the other half focused on working in small groups on the exercises in this unit, using digital materials and applications. The digital resources were classified according to levels of difficulty (development, reinforcement, and extension) as they were part of the Erasmus+ Increasing Mathematical Attainment in Schools (IMAS) project, funded by the European Union. The teacher granted access to the digital applications and exercises. The teacher also provided guidance to the students on how to use these tools so they could increase their level of commitment to learning and complete more tasks than requested, either to add additional homework or to improve their grades.

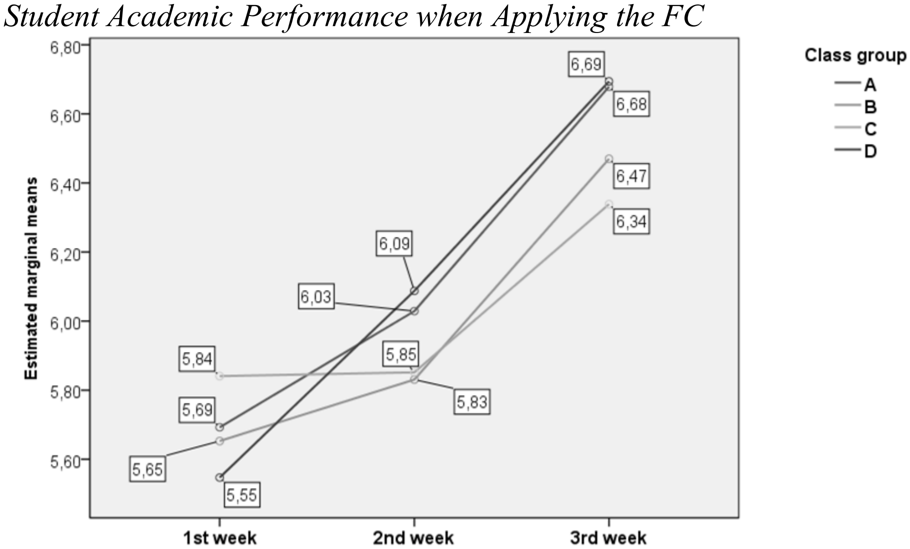
Results

Analysis of Academic Performance and Predictor Variables

Figure 1 shows the average grades of the four class groups, for each time the data was collected at any data point. At the beginning (first week), the students had achieved an average score of between 5–6 points out of 10 for all groups. At the end of application of the FC methodology through virtual sessions (3rd week), the students' grades had increased slightly by a few tenths of a point in all groups.

Figure 1

Student Academic Performance when Applying the FC



In relation to the students' grades, normality was found in the grades (Kolmogorov-Smirnov > .05). The Box's M test (M = 22.765; p > 0.05) allowed us to accept the hypothesis of equality of variance-covariance matrices. We therefore conclude that both groups are equal. Levene's test determined that the assumption of homogeneity of variances was met, in the three within-subjects factors: first week, F (3, 109) = 1.158 p. = .329; second week, F (3, 109) = 1.303, p = .277; and last week, F (3, 109) = 1.303, p = .277. Finally, Mauchly's test of sphericity was significant, failing to meet the assumption of variance sphericity (W = .275; X2 = 139.279; p < .05). Therefore, from now on the calculated significances will be interpreted with the Greenhouse-Geisser correction.

The results of the repeated measures mixed ANOVA indicated the existence of main effects on the factor "time of application of the Flipped Classroom methodology", F (1.160, 126.404) = 44.642, p < 0.005. However, no significant interaction effects were found between the within-groups factor and the between-groups factor, F (3.479, 126.404) =.270, p > 0.05. The pairs comparison allowed us to detect whether significant differences existed between the three points in time at which the students were assessed. This was done by adjusting for error using the Bonferroni method. Significant differences were found to exist between the first test and the second moment (p = .016), between the second and the third moment (p = .001), as well as between the first and the third moment (p = .001).

In order to check which predictors were significant for the academic performance of students (Table 3), we used a variety of statistical tests, depending on the design of the variable. A predictor analysis was performed, considering the scores of the last exam (post-test 3), i.e., at the end of the last week of the research. Regarding the gender of the students, the t-Student test determined that there were no significant differences in the scores (t = -1.205; p > .05), where the male sex (M = 6.75) stated a slightly higher mean than the female gender (M = 6.44). In relation to not achieving the grade for mathematics, significant differences were found (t = -7.158; p < .05), where students who had ever failed (M = 5.15) had a lower grade than students who had never failed (M = 6.90), with a large effect size (Cohen's d = -1.672). Regarding the influence of the education of both the father and the mother on their children's academic performance, Spearman's correlation was applied. It was found that there was a positive and significant correlation, both with the educational level of the father's education (r = .342), but especially with that of the mother (r = .579). Finally, a positive and significant correlation was also found about effort made towards mathematics (r = .327), but no significant correlation was found with the methodology satisfaction.

Table 3
Description of the Analyzed Predictors of Academic Performance

- Gender: male (1); female (2)
- Have you ever failed mathematics in secondary education? Yes (1); No (2)
- Father's/mother's education: from "No education" (0) to "Doctorate" (7)
- Effort towards mathematics: Likert scale from 1 to 10
- Satisfaction about the methodology: Likert scale from 1 to 10

Analysis of the Flipped Classroom and Virtual Sessions

Figure 2 shows the students' perceptions (arithmetic mean) before and after applying the FC methodology and using the digital resources for the virtual sessions. For the FC dimension, a significant increase in student perceptions was observed from the beginning of the project until its completion, both for the female gender (Z = -5.420; p < .05) and for the male gender (Z = -2.927; p < .05). In a comparison between both genders, no significant differences were found at the end of the project (U = 1145.000; Z = -1.502; p > .05). For the virtual sessions dimension, a significant decrease in student perceptions was found between the beginning and the end of the project, both for the female gender (Z = -7.383; p < .05) and for the male gender (Z = -4.990; p < .05). In a comparison between both genders, no significant differences were found at the end of the project in this dimension either (U = 1123.000; Z = -1.627; p > .05). As no differences were found between the genders, the analysis of predictors will be carried out on a general basis, without distinction between the genders.

Figure 2
Learners' Perceptions of FC and e-Learning

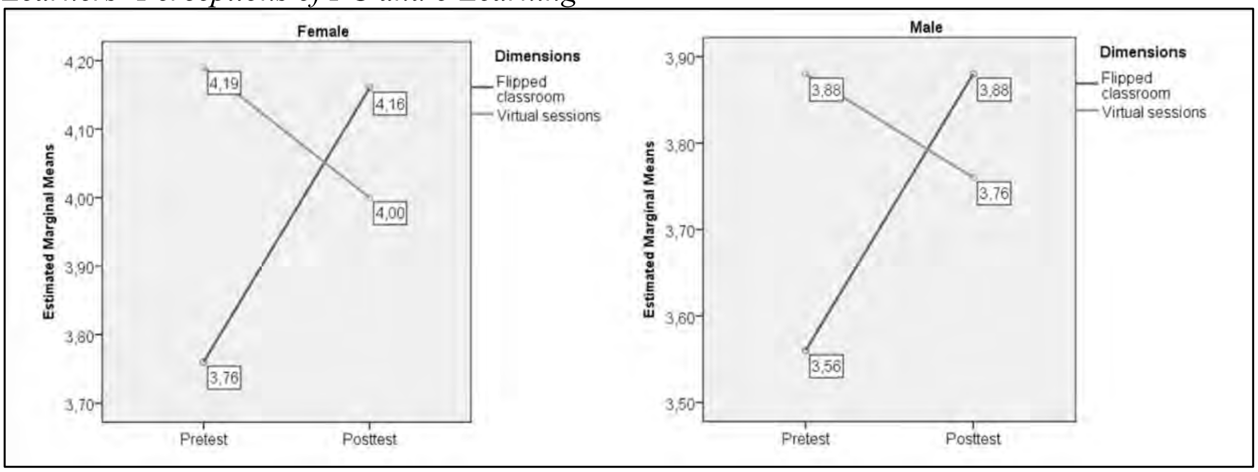


Table 4 shows the predictors analyzed in the students' perceptions of the FC. As these are ordinal variables, Spearman's correlation was used. Regarding the context of the family environment that would be suitable for working with this type of methodology, the students required a suitable home environment to continue with the sessions (M = 5.11), which states a positive and significant correlation (r = .649), with a moderate effect size. With respect to autonomous learning, students did not feel entirely competent to carry out their learning by themselves, with a medium perception (M = 4.20), not finding a significant correlation (r = .090; p > .05). Finally, students did not feel very motivated to carry out their educational process (M = 3.78), with a significant and negative correlation with perceptions of the benefits of FC (r = -0.570), with a moderate size.

Table 4
Description of the Analyzed Predictors of FC

- Family environment context suitable for working on FC. (Likert scale from 1 to 10)
- Autonomous learning (I learn very well on my own). (Likert scale from 1 to 10)
- Motivation level in learning mathematics, due to being in lockdown. (Likert scale from 1 to 10).

Table 5 shows the predictors analyzed in the students' perceptions of the virtual sessions. Depending on the design of the variable, different statistical tests were applied. Regarding the type of device used to connect to the virtual sessions, significant differences were found (x2 =

38.204; $p < 0.05$), where the students' use of smartphones obtained a lower mean (M = 2.39) compared with digital tablets (M = 3.04) and laptops (M = 4.21). Regarding the opportunity to view the theoretical sessions once more, significant differences were found (U = 354.000; $p < .05$), where students who re-watched the sessions obtained more favourable perceptions (M = 4.85) than those who did not re-watch them (M = 3.15). The frequency of use of the webcam was medium (M = 3.84), although there was no significant correlation between this use and the student's perceptions of the virtual sessions. The frequency of turning on the microphone was slightly below average on the 7-point Likert scale (M = 3.26), and there was a significant correlation with student perceptions (r = .575), with a moderate impact. Finally, the frequency of use of the videoconferencing platform chat was medium-high (M = 3.90), although there was no significant correlation.

Table 5

Description of the Analyzed Predictors of Virtual Sessions

Which technological tools do you use to participate in the virtual sessions: Smartphones (1); tablets (2); laptops (3)?
Do you usually watch the pre-recorded videos again? (yes/no)
How often do you usually turn on the web cam for virtual sessions? (Likert scale from 1 to 10)
How often do you turn on the microphone to ask questions? (Likert scale from 1 to 10)
How often do you use the Hangout chat to ask questions? (Likert scale from 1 to 10)

Taking into consideration all the statistical analyses carried out to meet the research objectives, the main results found can be seen in Table 6.

Table 6

Main Research Results

Study Purposes	Main Findings
Analyze students' academic performance when using FC	-Positive effect on student academic performance from pre-test and post-test
Know the perceptions of students about the use of FC and virtual sessions	-Student satisfaction with FC increased between the pre-test and post-test -Student satisfaction regarding the use of virtual sessions decreased between the pre-test and post-test
Identify significant predictors in academic performance of students and in their perceptions about FC and use of virtual sessions	***Academic performance*** -Gender not a significant predictor, although males had better grades -Failing math subject or the effort in learning this math had a significant influence, together with educational levels of parents ***Perceptions about the FC*** -Gender not a significant predictor, although females held more favorable perception -Having a good family environment to carry out this methodology virtually had a positive effect, while motivation to learn mathematics in a period of confinement had a negative effect ***Perceptions in the use of virtual sessions*** -Gender was not a significant predictor, although the females obtained more favorable perceptions -Types of technological devices used to participate in sessions influenced perceptions of the students, as did viewing pre-recorded videos

Discussion

When face-to-face teaching in secondary education was impossible in Spain, due to the restrictions caused by COVID-19, this research was aimed at analyzing both the impact of FC on students' performance in the subject of mathematics and their perceptions of this methodology and the use of digital resources in virtual sessions. For both aspects, predictors affecting the results have been identified.

Focusing on the academic performance of mathematics students when implementing the FC methodology, the results point towards a positive impact on academic performance, similar to what has been found by other authors (Galindo-Domínguez, 2021; Guillen-Gamez et al., 2019; Strelan et al. 2020; Wagner et al. 2020). This increase in grades mounts up progressively over the time of FC implementation, with grades improving significantly week-on-week. This may be due to the adjustment time required both to achieve positive results when switching from a traditional methodology to FC, in line with Lo & Hew (2017), and to adjust to the pace and interests of the learners (Guillén et al., 2020; Limniou et al., 2018).

As for predictors affecting performance, the male gender presents better grades, a common trend in mathematics according to related literature (Abín et al., 2020; Gomes et al., 2020). These results are similar to the study by Guillén-Gámez et al. (2019) but contrary to Chiquito et al. (2020). Nevertheless, gender does not show significant differences, coinciding with the work of several authors (Cho et al., 2021; Kadry & El Hami, 2014; Onojah et al., 2019). Both the fact of failing the subject of mathematics and the effort devoted to it do cause significant differences, with the performance of students who have never previously failed this subject being higher, as they make more of an effort, in line with the ideas proposed in the work of Gjicali & Lipnevich (2021). In addition, the educational level of the parents correlates positively with performance, which may be due to the importance that the family attaches to the study of mathematics. This coincides with the work of Meza-Cascante et al. (2021).

With a primary focus on student perceptions, we focused initially on FC users. We found that student satisfaction with FC has increased between the beginning and the end of the study, corroborating the findings of the study of Yang (2017) but contradictory to the results of Lape et al. (2014) and Young (2015). Looking at the gender factor, girls show higher satisfaction with FC, similar to the findings of Colomo-Magaña et al. (2020) but differing from those of Aljaraideh (2019). Despite this increase in scores, no significant differences in perceptions were observed between the sexes, as has occurred in other studies (Gómez et al., 2015; Kazu & Kurtoglu, 2020; Stratton et al., 2020). Among the predictors, it is worth highlighting how a good family environment and context correlates significantly with a better perception of the implementation of FC, coinciding with the statements of Mengual-Andres et al. (2020), as the educational process through FC requires an ideal working environment for viewing content in digital format, especially if teaching is being done remotely. Regarding students' motivation to learn mathematics while in lockdown, the perception is significantly negative, with contradictory results in the study of López-Belmonte et al. (2019). These results may be due to the social pressure exerted by the pandemic when students are in lockdown and cannot leave home for several months. These results should be interpreted with caution: as they depend on the context in which the learning process takes place, motivation may vary.

As to the general perception of virtual sessions, in this case the participation of both sexes tailed off quite soon from the start until the end of the project, with a slightly higher rating by the female sex, as in the study by Peytcheva-Forsyth et al. (2018). No significant differences in perceptions between the sexes were observed in this respect. Regarding the predictors, the type of electronic device determines the assessment of the virtual sessions, with significant differences between them. Smartphones were rated at the bottom of the scale, while students who use laptops gave a better perception compared to tablet users. These findings coincide with those of Liberatore & Wagner (2021). As to devices associated with the interaction in the online session (camera, microphone, and chat), the results reflect an average use, with only the microphone correlating positively with the perception of the virtual session. Both the repeated watching of pre-recorded videos and the use of devices to interact in the sessions reflect that more participative and engaged students have a better impression of the virtual sessions, corroborating the relationship between the use of ICT resources with higher motivation and academic performance in mathematics (Gilar-Corbi et al., 2019; Gómez et al., 2020; Hammoudi, 2019; Hu et al., 2018; Lipnevich et al., 2016; Sharp & Hamil, 2018).

Conclusions

During the first period of lockdown when face-to-face education was impossible, different methodological proposals were deployed, among which FC stands out for its asynchronous design outside the classroom (theory) and synchronous sessions (virtual), focused on resolving doubts and completing tasks. This study focused on the teaching of mathematics in secondary education, showing the positive impact of FC on the learning process. The findings of this research indicate that the implementation of FC in an online context improves the academic performance of students in this particular subject. We found that the longer the duration of the study, the more efficient this method became. In addition, the positive perceptions of FC reinforce the idea of its usefulness for teaching mathematics in an online context, something that was not always evident in face-to-face training. As for the use of technology in the virtual sessions, satisfaction decreases as the project progresses, which may be caused by online training fatigue during the pandemic. Factors such as the parents' educational level, the family environment and the type of device used to attend the virtual sessions, with a significant positive correlation, or the effort and motivation towards the subject, which could have a significant negative correlation, become predictive factors of the students' performance and perceptions.

As to the limitations of this study, factors to be taken into consideration include the size of the sample and its non-randomness. This makes it difficult to generalize the results and, for future studies, it will be necessary to increase the number of participants and to carry out non-purposive sampling. The duration of the research should also be noted, since the FC method gains in efficiency if it is applied to a wider range of subjects. This is another aspect to be considered for future studies. Other subjects could be added to the study to avoid the negative attitudes to and difficulties in learning mathematics. In addition, if this subject is studied further, it may be interesting to address different educational stages (primary or higher education) that have also experienced the change from face-to-face teaching to an online format linked to the pandemic. We have tried to ascertain the predictors of ICT as used in virtual sessions and to associate these with the physical, social and psychological, consequences caused by lockdown and other restrictions implemented during COVID-19, in order to determine the impact of this global phenomenon on the aptitude and predisposition of students to learn in an online environment.

Declarations

Prior consent to participate in the study was requested from the students, considering the Helsinki Declaration.
The authors declare that they have no competing interests.
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