Education in the Knowledge Society 22 (2021)

Education in the Knowledge Society

journal homepage http://revistas.usal.es/index.php/eks/

Ediciones Universidad Salamanca

E-Cooperative Problem Solving as a Strategy for Learning Mathematics during the COVID-19 Pandemic

La resolución de problemas e-Cooperativo como estrategia para el aprendizaje de las matemáticas durante la pandemia de la COVID-19

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ARTICLE INFO

Keywords:
Cooperative learning
Distance learning
COVID-19 pandemic
Self-determination theory
Mathematics education

ABSTRACT

The article presents the benefits of cooperative learning in mathematics in distance teaching conditions during the COVID-19 pandemic. In longitudinal studies, six math teachers formed a collaborative network and developed scenarios for three projects to be implemented by students on an educational platform. During their eight-week implementation, the principles of cooperative learning, using the methodical implications of the self-determination theory (SDT), have been followed. Among students (N = 104) from five sixth grades of primary school, measurements of social-emotional skills were carried out using the Distance Learning Climate questionnaire (DLC-21). The students have shown a high level of mathematical performance (84.8%), a significant increase of the relatedness to the group and a significant decrease in the sense of situational fear. The results also indicate a high level of students' sense of competence and satisfaction associated with implementing mathematical projects.

Palabras clave:
Aprendizaje cooperativo
Aprendizaje a distancia
COVID-19
Teoría de la autodeterminación
Educación matemática.

RESUMEN

El objetivo del artículo es presentar los beneficios del aprendizaje cooperativo en matemáticas en condiciones de enseñanza a distancia durante la pandemia de la COVID-19. En estudios longitudinales, seis profesores de matemáticas formaron una red colaborativa y desarrollaron escenarios para tres proyectos que pudieran ser implementados por los estudiantes en una plataforma educativa. Durante su implementación, de ocho semanas, se han seguido los principios del aprendizaje cooperativo, utilizando las implicaciones metódicas de la teoría de la autodeterminación (TED). Entre los estudiantes (N = 104) de cinco sextos grados de la escuela primaria, las mediciones de habilidades socioemocionales se llevaron a cabo mediante el cuestionario de Clima de Aprendizaje a Distancia (DLC-21). Los estudiantes han mostrado un alto nivel de rendimiento matemático (84,8%), el aumento significativo de la afinidad con el grupo y la disminución significativa de la sensación de miedo situacional. Los resultados también indican un alto nivel de sentido de competencia y satisfacción de los estudiantes asociado con la implementación de proyectos matemáticos.

1. Introduction

Mathematics is a specific field of knowledge, having a spiral, cumulative structure that makes its learning required steadfast, internal discipline from the students and quite often it may be fraught with difficulties (Scheiner, 2016). Although most students like mathematics at the beginning of school education, a large proportion of them declare concerns about mathematical performance and even math anxiety (Carey et al., 2016) and this phenomenon is common in

Recibido, 29/11/2020. Revisado, 2/4/2021. Aceptado, 19/04/2021. Publicado 16/12/2021
e-ISSN: 2444-8729

many countries (Lee, 2009). The results of research on math anxiety (Ashcraft, 2002) and meta-analysis (Namkung, Peng, & Lin, 2019)) indicate the presence of a its relationship with mathematical achievements (Dowker, Sarkar & Looi, 2016). It is also known that relatively few students choose mathematics as a course of their further educational and professional career (Ashcraft & Moore, 2009). At the same time, mathematical skills, and especially problem solving, are useful not only during education period, but also in various situations of adult life in 21st century (Cuevas, Nitoumanis, & Fernandez-Bustos, 2018; Oonk, Verloop, & Gravemeijer, 2015).

That is why it is worth looking for solutions so that mathematical education would be effective and enjoyable for many students not only at the beginning of the school path, but also at the further stages of their education. The ability to perceive mathematical tasks as challenges rather than threats leads to shaping resistance to failure and reduces fear of failure, and thus also raises students' mathematical achievements (Ramirez, Shaw, & Maloney, 2018).

Self-determination theory (SDT) has proved to be one of the theoretical frameworks effective in this process. Its authors (Ryan & Deci, 2000) emphasise the role of internal motivation in the processes of self-determination. Based on education (Niemiec & Ryan, 2009), including mathematical education (Hagger et al., 2015; Lohbeck, 2018) this desired type of motivation may be developed (Sutter-Brandenberger, Hagenauer, & Hascher, 2018) by creating a learning environment that meets the three universal needs of learners: relatedness, competence, and autonomy (Knopik & Oszwa, 2020). It seems that these conditions could be met by cooperative learning (Gillies, 2016).

During the COVID-19 pandemic, most countries suspended their stationary school activities in spring 2020. Education was transferred to virtual platforms, requiring students and teachers to adapt to the new teaching/learning formula quickly. The teachers have faced the challenge of full implementation of the core curriculum. Many of them had decided that it has been possible to apply the same teaching strategies as they have done so far in virtual education - only the media have changed. This approach has turned out to be naive, and soon both the teachers and the students realised that e-learning requires entirely different teaching methods and techniques than those that built stationary practice (Allen, Rowan, & Singh, 2020). Additional essential factors that teachers could not be indifferent to are a sense of uncertainty, stress and anxiety caused by students during the pandemic and their fears and concerns (Talidong & Toquero, 2020). In many countries, discussions have been initiated about the priorities of distance learning during the COVID-19 pandemic: acquiring new knowledge and skills in the curricular content contra equipping the students with immunity resources to deal with the current situation.

In this context, in the own study an attempt has been made to apply a cooperative learning strategy (Johnson & Johnson, 2003; Gillies, 2004; Slavin, 1980) as one that could strengthen the link between the situation of social constraints and the need for effective mathematics teaching (Slavin, 2013), bringing in addition to substantive skills in solving mathematical problems (Martin & Towers, 2015), also other benefits in the form of internal motivation (Gillies, 2003b), mathematical resilience (Daneshamooz & Alamolhodalel, 2012) and the development of social resources and communications (Gillies, 2003a).

The forced distance teaching situation has been treated as an opportunity to check the effectiveness of e-cooperative learning strategies (Harrison, 2018) to become a permanent element of teaching in the future. Another advantage of e-cooperative learning (Clark-Wilson, Robutti, & Sinclair, 2014) is its attractiveness to students compared to traditional teaching methods since it ensures active involvement in mathematical discourse (Johnson & Johnson, 2002). In addition, the increased frequency of contacts between students evoked by the cooperative nature of learning has a positive effect on stress and fear mitigation (Topping et al., 2017).

2. Cooperative learning: from the sources to e-practice

Cooperative learning has been derived from the theory of socio-cultural development by Vygotsky (1980), according to which in the proximal development zone, the student may, with the help of others, acquire knowledge that s/he would not be ready to learn on her/his own (Webb, 1991). Collaboration and cooperation involve working together to achieve common goals (Johnson et al., 2014). Cooperative learning is the joint work of students in small groups (3-4 people) with precisely defined goals and individual responsibility of each team member for partial tasks (Gillies, 2003a). There are many methods of cooperative learning (Slavin, 2014), which fall into two categories: a) structured team learning and b) informal group learning. Structured team learning has three characteristics: 1) team reward, 2) individual accountability, and 3) equal opportunity for success (Gillies, 2003b; Slavin, 2015). Team reward means receiving a collective award, a certificate for achieving a common goal. Individual accountability means the team's dependence on each member's learning and his/her independent test possibility without peers (Johnson & Johnson, 2003). Equal opportunities for success are aimed at each student's participation in the final result of the teamwork by improving their previous achievements (Slavin, 2014). This means that students with high, average, and low achievements do not compare but overcome their weaknesses and raise their previous scores (Gillies, 2016).

Effective cooperative learning contains five components built into its structure (Gillies, 2016): 1) establishing and structuring positive interdependence so that students understand that they are interdependent during work, 2) facilitating promotive interaction, encouraging to make an effort to implement the task so the team could succeed, 3) encouraging individual responsibility for the partial task of each student, 4) explicit teaching the appropriate social skills, which includes: active listening, sharing ideas and help, constructive commenting on colleagues' ideas, democratic decision making (Johnson & Johnson, 2009), 5) encouraging students on group processing, which relates to the reflective view of the team progress and work as well as the relationships prevailing in it during the implementation of the project or joint task solving (Gillies, 2003a).

The teacher's role in cooperative learning differs from traditional teaching (Webb, 1991). It involves structuring the groups and the tasks so that students know their goals well (Gillies, 2003a). It also includes promoting intra-group discussions, helping students engage in interactions and work collectively, encouraging them to listen to each other, explain to each other, and answer all questions asked in a team (Johnson & Johnson, 2009). In addition to promoting cooperative learning, the teacher is also a mediator between students during its implementation (Gillies, 2003b).

Research meta-analyses on cooperative learning (Johnson & Johnson, 2003) contain evidence on the effectiveness of this education method. A result of its application, students absorb knowledge and develop skills effectively (Kunter et al., 2008), solve problems and communicate with each other more efficiently (Kuhn, 2015)), accept cultural and minority differences (Hurley, Boykin, & Allen, 2005), feel motivated to work together and to achieve group and individual goals (Magne & Deci, 2005; Sengupta-Irving, 2016), respect others and appreciate their participation in a collective task (Gillies, 2003b), resolve disputes democratically (Gillies, 2016), take into account the viewpoint of others (Slavin, 2013), they feel members of the team they identify with (Webb, 1991), they have a sense of autonomy in the selection of techniques and ways to solve the problem (Brandenberger, Hagenauer, & Hascher, 2018), they feel competent in the tasks entrusted to them, due to which they are more involved in the task (Carmichael, Muir, & Callingham, 2017), work constructively and take care of interpersonal relationships in the group (Corkin, Ekmekci, & Parr, 2018; Gillies, 2004), show greater resilience to difficulties and failures (Daneshamooz & Alamolhodaei, 2012).

The use of modern IT tools, supporting education in efficient students' problem-solving strategies and their training in arithmetic skills and data processing speed, already has a well-established research body (Leung & Baccaglini, 2017; Drijvers et al., 2010; Lagrange & Erdogan, 2008). In the case of traditional teaching aids use, each time e-tools have been applied. There should be a specific methodological goal behind it, not just pleasure or cultural compulsion to use modern technologies (Juan et al., 2012). Therefore, the professional incorporation of contemporary technologies into mathematical education requires thorough preparation for teachers (Elijah, 2012; Sysło, 2014).

Researchers emphasise the need to implement a constructivist e-learning paradigm so that interactive tools favour the activation of knowledge-making processes and not serve the continuation of modern transmission and passive teaching (Koohang, Riley, & Smith, 2009; Ahn & Edwin, 2018). These findings clearly show that the automatic switch of teachers from the stationary teaching model to distance education during the COVID-19 pandemic without proper competence preparation and system support entails a severe risk of chaotic and unordered methodical e-teaching (Sysło & Kwiatkowska, 2008).

The cooperative learning method of mathematics in the e-environment has been well suited to the educational project method, which sources go back to the tradition of the American philosophy of education, influenced by the idea of pragmatism (Dewey, 1910; Kilpatrick, 1918). The main component of the project method has been students' activity supported by a teacher who has become a consultant more than a knowledge transfer expert (Knoll, 1995). The project method has been closely related to students' experience and intended to develop a strategy of describing and learning about this experience. Hence, starting with the choice of the topic, through its operationalisation, selection of activities, presentation of effects and finishing on their evaluation, the initiative should be on the side of the learners, not the teacher (Waks, 1997). Such an approach rooted in the pragmatics of life has been an effective strategy for teaching mathematics (Barnes & Venter, 2008), because it has demonstrated a non-academic perception of mathematical knowledge and skills (Li et al., 2019). Project-based learning focuses on building communities of practice' among students, teachers, and people outside the school environment (Williams, 2017). The educational experience encompasses the intellectual, social, emotional, physical, and spiritual growth of the whole child, not just academic growth (Matriano, 2020). Each project has been based on a multi-step procedure for solving the problem, described in five steps by John Dewey:

1) the student observes a problem in his/her activity ('a felt difficulty'); 2) the student defines the problem in the activity ('its location and definition'), 3) the student considers various possibilities to solve the problem in the activity ('suggestion of possible solution'); 4) the student outlines a solution to the problem in the activity relying on his/her own thinking ('development by reasoning of the bearings of the suggestion') 5) the student tests his/her idea experimentally to solve the problem (Sutinen, 2013, p. 1046).

Such an approach to solving mathematical problems that can take the formula of hybrid thinking both in cooperative and individual form (the reflection effects of the individuals are confronted on the forum) activates the process of interiorising mathematical contents, making them not imposed program contents, but self-developed strategies and conclusions.

Having considered the potential effectiveness of implementing mathematical e-project and the possibility of recommending it as a good, verified educational practice, two research objectives have been formulated:

a) The assessment of the effects of cooperative mathematical problem solving in the dimension of mathematical performance, competence in mathematics and satisfaction with mathematical classes, relatedness to the group increases and situational fear decrease.
b) The critical analysis of the possibilities of implementing the SDT concept in mathematics teaching while building the student's resilience resources as crucial factors both in cumulative mathematical education and in the stressful pandemic situation.

3. Method

The study sought out the answers to the following questions:

1. To what extend the e-cooperative mathematics learning strategy introduced in the COVID-19 pandemic students' isolation could be efficient in acquiring their knowledge and skills, measured by their mathematical performance?
2. To what extend this e-learning of mathematics introduced in the COVID-19 pandemic isolation could be effective in formatting students' competence and satisfaction with acquired mathematical knowledge?

Taking into consideration the potential benefits of using the project method in SDT approach, another research question has been formulated:

3. Could be the tested e-learning mathematics strategy introduced in the COVID-19 pandemic isolation productive in the scope of: a) moulding students' relatedness to the team; b) mitigating the fear associated with the quarantine caused by the COVID-19 pandemic?

It is worth underlying that the research idea has been the direct result of the expression of the real methodological need that appeared in the first week of stationary school activity suspension in Poland among mathematics teachers who belonged to the cooperation and self-education network. In this sense, the study has been applicative and practically useful in its character.

4. The study participants

The study was conducted in the test-retest model in the eight-week-period from 20th March until 19th May 2020 among 104 sixth grade students, aged 12-13 (48 girls, 56 boys) from five Polish primary schools (3 urban, 2 rural). The number of every class was similar and ranged from 18 to 23 students.

Care was taken to ensure parents were thoroughly informed about the objectives and course of the study, and appropriate consent was obtained (during an online meeting using the Teams platform, additional scans of written consents were sent back). Research assumptions have been consulted among two mathematics education methodologists and two psychological and pedagogical counselling centres (trauma-psychologists) employees to identify potential risks related to students' participation in the study and develop strategies for their reduction. The inclusion of extra warm-up in the project, rounds of chat statements and a dictionary of the most pleasant words and sentences has been added to the study as the result of this consultation.

5. Measures and procedure

The study has been carried out in the test - retest model using two measures:

a) *Mathematical Performance Test*, measuring the students' assumed outcomes of the curriculum for the sixth grade.
b) *Distance Learning Climate Questionnaire (DLC-21)*, made of 21 items in four scales: Relatedness, Competence, Satisfaction, Fear described in detail in Table 1.

The longitudinal study was carried out in three stages:

1) Initial measurement of the students' relatedness to the team and their level of situational fear, carried out using the electronic version of the tool (Relatedness and Fear scale from DLC-21).
2) Eight-week implementation of three mathematical projects (described in table 2) on the *Teams* platform using the *epodreczniki.pl* platform maintained by the Ministry of National Education containing free interactive materials for teachers and students.
3) Measurement of a) mathematical performance and competence and satisfaction in relation to conducted maths classes, as well as b) final measurement of students' relatedness to the team and their level of situational fear at the end of the study; measurements were made with the use of DLC-21 electronic version.

Table 1. Structure of the DLC-21 questionnaire.

Scale	**Items**	**Dimension description**	**Internal consistency (Cronbach's alpha)**
Relatedness	8	Subjective assessment of the current intensity with the group in aspects: emotional (joy of mutual contacts) and purposeful (common goals to be achieved)	0.89
Competence	4	Subjective assessment of the sense of learning; student conviction about the value and usefulness of acquired knowledge and skills	0.81
Satisfaction	4	Degree of student satisfaction of participating in a given learning form	0.92
Fear	5	Subjective assessment of the sense of threat and uncertainty associated with the current life situation	0.94

Note: The items were taken from the Social and Emotional Development Profile – PREiS (Domagała-Zyśk, Knopik, & Oszwa, 2017).

Mathematical projects preparation and implementation in the study. In the first week of suspension of stationary teaching in Polish schools, a group of six mathematics teachers, working in a network of cooperation and self-education, approached researchers from the Maria Curie-Sklodowska University in Lublin with a request for consultation on the development of an optimal strategy for teaching mathematics on-line in a primary school. The teachers formulated three difficulties (barriers) they identified in distance mathematics teaching: a) mathematics is a subject that requires modelling new skills through direct interaction with students; b) quarantine means social isolation and the potential risk of students' loneliness and social deprivation; c) it is not possible to design distance education on the model of stationary education, the transmission teaching mode must give way to an approach that activates the student and affirms his/her autonomy.

Based on the challenges formulated by the teachers, an eight-week mathematical program for sixth-grade students has been designed. The online project method has been considered as the one that allows the simultaneous development of mathematical and emotional-social competencies because of cooperative learning as its crucial component. It is worth understanding that the way teachers prepare projects (from the diagnosis of difficulties to the development of an action strategy and its implementation) has also been an example of cooperative learning. Researchers working with teachers supported their activities by conducting a 5-hour methodical workshop presenting the possibilities of applying the SDT concept in learning mathematics (Knopik & Oszwa, 2020). In addition, teachers were offered mentoring assistance at every stage of the project.

Working on implementing the core curriculum effects into project activities while considering the assumptions of SDT (care for satisfying the needs of relatedness, competence, and autonomy) has been an important phase of the training. The interdisciplinary nature of the projects required the involvement of other teachers: biology and computer science. A detailed description of the projects concerning the core curriculum has been presented in Table 2.

Table 2. Project titles, activities and implementation of the learning outcomes required in the curriculum.

Project title	**Activities**	**Implemented/achieved learning outcomes from the curriculum**
Geometry almost perfect in art	1. Class division into groups by field of art: painting, sculpture, architecture, graphics. 2. Works of art review with the extraction of geometric figures (reconstruction of the artefact structure) 3. Overview of curiosities from the history of art: the Egyptian triangle, the golden number, and the pyramids, anamorphisms, illusionism, cubism, tessellation, fractals, vector graphics. 4. Composing text tasks inspired by art. 5. Creativity training (based on J. Guilford's Distant Consequence Test): *If the architect did not know mathematics, then ...* *If the sculptor did not know geometry, then ...* In addition to verbal statements, students design deformed works of art in a graphic program 6. Students' own creativity based on mathematical dictation: the teacher provides descriptions of geometrical figures and their arrangement; based on this information students create their own compositions, look for thematic connections and finally give the work a title.	Mathematics - the student: 1) Knows the most important properties of geometric figures and indicates their symmetry axes. 2) Recognizes solids in practical situations, indicates selected solids among solid models. 3) Recognises the grids of straight prisms and pyramids. Other school subjects: Visual arts - the student: 1) Recognizes selected, the most important works from the achievements of different nations. 2) Distinguishes features and types of compositions in nature and finds them in the works of masters.
SOS nature - ecological calculations	1. Butterfly effect - explanation of the concept 2. Round of (not) obvious student-generated questions Is it worth to be eco? Is it profitable to collect rainwater? Is it worth turning the water off when brushing your teeth? Is it profitable to segregate garbage? What gives the user to turn the computer off while s/he doesn't use it? **3. How do you calculate it? Elaboration of eco-profit calculations with the participation of biology teacher.** **4. Carrying out calculations.** 5. Preparation of posters summarizing calculations. 6. Preparation of materials promoting the benefits of pro-ecological behaviour using calculations carried out.	Mathematics - the student: 1) Writes, reads, compares, adds and subtracts multi-digit natural numbers in writing and with a calculator. 2) Interprets natural numbers on a number line. 3) Writes binomial expressions as decimal fractions and vice versa. 4) Calculates the number of which a part is given (designates the whole of which the part was specified by a fraction). 5) Calculates the percentage of a given quantity. Other school subjects: Biology - the student: 1) Analyses the impact of man on biodiversity. 2) Justifies the need to protect biodiversity.
Statistics on the trail of truth	1. Analysis of popular press and websites articles about Poles' opinions on a selected topics (after discussion students indicated: vegetarianism, car ownership, sports activity) 2. General confrontation of collected analyses, noticing discrepancies, searching for their sources. **3. Identification of the data collection method in the cited articles and their constructive criticism.** 4. Own study: topic selection, method development, conducting the study, results analyses, presentation - in each class students studied the same phenomenon in four groups- online food shopping via the internet during quarantine time; reaching different conclusions, they tried to explain discrepancies, referring to the acquired knowledge of the basics of statistics	Mathematics - the student: 1) Collects and organizes data. 2) Reads and interprets the data presented in the texts, tables, diagrams, and charts. 3) Uses mathematical calculations in analysing phenomena from one's own life. Other school subjects: Computer science - the student: 1) Uses a spreadsheet when solving tasks related to simple calculations enters data into the worksheet, formats the cells, defines simple formulas, and selects charts for data and calculation purposes.

Note: The table shows in bold the stages that required higher teacher involvement in student activity control; Source: Own study resources.

The projects were implemented in the 25/75% formula, i.e., 25% of the time was allocated to online meetings with the entire class with the participation of the teacher/s (these project phases have been shown in bold in Table 2), while 75% of the time had the character of the meetings in small groups. In total, over eight weeks, one student devoted an average of 39.5 hours to the project. The forms of implementing cooperative learning and their percentage share in the total time allocated to the project have been presented in Table 3. The emphasis needs to be placed on the highest frequency of joint file editing by the students and their presentations (prevailing students', not teacher's activity).

Table 3. Forms of activity during cooperative learning and their percentage share.

Activity	%
Lecture / teacher presentation	5%
On-line consultations with the teacher	8%
Lecture / students' presentation	18%
Discussion on the class forum (video)	11%
Joint editing of the file on the platform (comments, discussions in the file)	19%
Chat (2-3 people)	9%
Chat (4-8 people)	8%
Class chat	3%
Collecting sources and posting them on the platform for shared use	8%
Other, including student individual work	11%

Source: Own study results.

6. Results

Basic descriptive statistics regarding the measured variables have been presented in table 4. Students have shown high mathematical performance (on average 84.8% of the maximal possible number of points in the test). No initial measurement has been taken, as the test concerned new issues and has been treated as a standard way to verify mathematics learning outcomes. However, it is worth underlying that this result has been significantly higher than the previous data archived by the teachers for their classes (for all tests carried out in the first semester of the sixth grade, the average percentage result was 64.3%). In addition, the students have shown a high sense of competence (average score of 81.3%) and a high level of satisfaction with participation in e-cooperative mathematics learning classes (average score of 77.5%).

Table 4. Comparison of test-retest results for relatedness and fear.

Scale	N	Min	Max	M	SD	Wilcoxon Test
Relatedness (test)	104	10.00	26.00	17.96	3.39	z=-8.330; p<0.001
Relatedness (retest)	104	10.00	32.00	23.26	4.59	
Fear (test)	104	2.00	20.00	13.20	3.61	z=-6.996; p<0.001
Fear (retest)	104	4.00	20.00	11.16	3.46	

Source: Own study results.

Analyses of the significance of differences in test-retest measurements for team-relatedness and situational fear have been carried out using the non-parametric Wilcoxon test - ordinal nature of the data (Table 4). It has been shown that the results of retested measurements have been significantly different in comparison to the tested ones: higher in students' relatedness and lower in their situational fear.

It was also checked to what extent the controlled variables acted as predictors of mathematical performance. For this purpose, step regression analysis has been used. The obtained results in the form of a model have been presented in Table 5 and Table 6. The student's sense of competence and satisfaction with mathematical classes explains mathematical performance in approximately 56%.

Table 5. Regression models for dependent variable: mathematical performance (significance assessment).

Model		Unstandardised coefficients		Standardized coefficients	t	p
		B	Standardised Error			
1	(Constant)	32.483	2.583		12.574	p<0.001
	Competence	1.677	.196	.647	8.565	p<0.001
2	(Constant)	23.826	2.652		8.984	p<0.001
	Competence	1.375	.176	.530	7.810	p<0.001
	Satisfaction	1.014	.169	.409	6.016	p<0.001
[a]Dependent variable: mathematical performance						

Source: Own study results.

Table 6. Step regression for dependent variable: mathematical performance.

Model	R	R-square	Adjusted R Square	Estimate Standardised Error
1	.647[a]	.418	.413	4.54
2	.756[b]	.572	.563	3.91
[a]Predictors: (Constant) Competence				
[b]Predictors: (Constant) Competence, Satisfaction				

Source: Own study results.

The student's assessment of the participation in other teachers' classes (i.e., a mathematics teacher from another school or a teacher of another subject) was also controlled. The results indicate that 54.8% of students rated this situation as unfavourable for them, 40.4% as favourable, and 4.8% had no opinion on this issue. In free statements, students emphasised that they had not met with the classes run by two different teachers so far, and it was strange for them, but in the end, it positively influenced the final effect of the classes, although the other teachers' presence slightly inhibited students' activity during the project.

7. Discussion

The obtained results have indicated that in terms of the effectiveness of knowledge transfer and mathematical skills anticipated to be implemented in the core curriculum, this method implemented during the COVID-19 pandemic has been efficient and allowed the students to obtain a higher achievement rate than in the case of mathematical performance in standardised school education (81.3% versus 64.3%).

According to the regression equation, the main predictors explaining the higher level of students' mathematical performance have been their sense of mathematical competence and satisfaction with participating in e-cooperating learning during a specific time of the COVID-19 pandemic. One of the components of the sense of competence is coping with problem-solving (in the study - mathematical problem solving) and the ability to seek and use the support of others (Domagała-Zyśk et al., 2017). As the results have shown, basing cooperative learning on the project method in the study has strengthened these competencies by:

a) Showing the students the connections between mathematical thinking and their everyday experience and the universality of the presence of mathematics in the knowledge of the world (e.g. biology, art history, sociology), which made it possible to see the non-school dimension of mathematics clearer; the statements on the sense of competence scale: *I see many benefits of participating in these classes; I feel that what I do in these classes will be useful for me in my life,* have been at most rated by the students.
b) Implementation of the team problem solving, during which at each stage the student could count on the support of peers and the teacher as the advisor; what was noticed, peer support has been adapted to the needs of the students both in the form of communication and translation strategies (mind maps,

drawings); this has been confirmed by the opinion of three teachers, completing the projects, who have found the most surprising fully accurate and original strategies for students, explaining difficult issues to each other; a critical variable for such a successful interaction was the collaborative process of repairing their shared understanding and reasoning anchored in mathematical properties of analyzed issue (Varhol, Drageset, & Hansen, 2021; Wake, Swan, & Foster, 2016).

c) The involvement of each student in the planning and implementation of classes - the commitment and the assumption of responsibility for the activities has been associated with the higher satisfaction flowing out from them (Deci & Ryan, 2010).

d) Activating dialogue as a method of mathematical problem solving - creating group maps of the problem and discussing its structure turned out to be the element of mathematical classes, which in the opinion of the teachers apparently has shown the difference of online classes during the COVID-19 pandemic in confrontation with standard practice (which is in line with the research of Oonk et al. (2015) and Sengupta-Irving (2016)).

e) Changing the teacher's function who has ceased to be an expert-lecturer but became an advisor (tutor) in the process of joint problem solving; moreover, this problem has not been the teacher's problem (as it used to be in the classroom so far), but the controversy/challenge identified by the student him/herself (for interiorisation of mathematical problems see (Kurniati et al., 2018)).

This result has been in line with the findings of the project method evaluators who have emphasised its effectiveness in learning mathematics provided that several criteria have been met (Bolt & Hobbs, 1989; Hmelo-Silver, 2004; Stoica, 2015): a) solving unknown types of tasks that give a chance to develop initiative and flexibility, and enable the use of a variety of strategies and skills; b) addressing issues in which information and conclusions should be drawn independently, and students are encouraged to develop critical thinking and creativity (van Oers, 2010; van Roekel, 2001); c) assuming responsibility for one's learning and self-dosing the methods (including free going beyond the core curriculum limit); d) discovering the interdisciplinary nature of knowledge.

The critical role of satisfaction derived from classes with the use of e-cooperative learning in the COVID-19 pandemic in the development of mathematical performance has been associated primarily with a) their non-standard character, b) using many channels of information transfer (hence the repeated students' statements: *It was not boring even for a moment*) as well as with c) the variety of possibilities activating the student, depending on his/her current preferences (watching a movie, chat, collecting data, mind map). This result has been in line with the results of observations made by Kunter et al. (2008), who stated that satisfaction (passion) for mathematics classes was related to the supportive social environment created by the teacher, where support was offered in difficulties, as well as conducting classes in proximal development zone (Vygotsky, 1980). According to the SDT assumptions (Deci & Ryan, 2000), challenges tailored to the student’s capabilities and needs allow him/her practical development. Such results have been consistent with similar conclusions in other studies (Blazar, 2015; Frenzel et al., 2009).

Cooperative mathematics learning during the COVID-19 pandemic has proved influential in moulding students' sense of relatedness to a class (cf. Magne & Deci (2005)) and reducing their situational fear caused by the pandemic. Project activities have allowed formulating common goals for implementation; by the concept of SDT (Niemiec & Ryan, 2009), they have been the base for the students' relatedness satisfaction (Ryan & Deci, 2017). Social interactions evoked by the need for joint learning have also reduced the fear of adapting to the new situation caused by the COVID-19 pandemic. During the project evaluation meeting, the students emphasised that joint problem solving gave them hope that everything could be dealt with in a team. Social support, which has been provided during cooperative learning in the COVID-19 pandemic, could have a universal role as the immune resource and resilience (Deci & Ryan, 2010) in dealing with the unusual nature of the quarantine situation.

Following the recommendations of external experts, the teachers supervising projects included exercises in online meetings to enable verbal expression of students' negative emotions during the COVID-19 pandemic. This relatively intimate atmosphere, which has developed between the students and the teacher in his/her new role of counsellor, caused a negative perception of the external teachers' participation in the classes. The idea of engaging an additional teacher to lead a group has been mainly aimed at stimulating the creativity and originality of students' thinking. However, only 40% of the students perceived this participation as beneficial for them. In the remaining 60% of cases, the students have perceived the external teacher as the one who inhibited their involvement and spontaneity. Therefore, the issue of the effectiveness of the additional teacher's participation in class would require more in-depth research in time after the COVID-19 pandemic.

According to the regression analysis, the sense of relatedness to the group during e-cooperative learning in the COVID-19 pandemic has not been a predictor of the students' mathematical performance. For mathematical achievements measured by the knowledge and skills test, the level of identification with the class does not have such direct significance as the sense of competence and satisfaction, which directly relate to the effectiveness of learning. The obtained findings could be treated as an example of such an approach to teaching, in which, in addition to developing mathematical competencies (the main one), it is possible to mould transferable resources and skills (the additional ones). Therefore, it seems crucial for the methodical practice that the development of transferable skills, necessary for students' life success, should not remain in opposition to mathematical skills and indirectly can even strengthen them. The result has evidenced this, showing that the students& fear reduction most strongly correlated with the sense of their relatedness (Spearman rho=0.42, p <0.001). A stressed student focused on fears is undoubtedly much less effective in learning, especially mathematics in the COVID-19 pandemic and regular education time. A large body of research has been available (Hembree, 1990; Oszwa & Szablowska, 2018), indicating that math anxiety has negatively correlated with mathematical achievements.

The collected reflections from the students and the teachers have shown that the necessity of teaching during the COVID-19 pandemic launched methodological activities that were not practised in standard conditions. The teachers pointed to the barriers to cooperative learning in standard conditions related to a) the limited duration of the lesson/period (45mins), b) the more substantial external pressure on the teachers to implement the core curriculum, c) the greater control by pedagogical supervision and d) the higher level of competition between the students. Therefore, if the cooperative mathematics learning strategy verified in this study during the COVID-19 pandemic is to be recognised as an applicable practice for stationary education, it might be necessary to conduct additional analysis of reported barriers and strategies for their reduction.

8. Conclusions

As the obtained results have shown, the methodology of teaching mathematics based on the idea of e-cooperative learning has been influential not only in the implementation of the assumed effects from the core curriculum but also in the field of re-education of situational fear raised by the COVID-19 pandemic and the increase of students' sense of relatedness to the group in this specific time and the development of their sense of competence in mathematics as well. These three are universal needs, which - according to SDT assumptions - lead to an increase in intrinsic motivation to learn (Vansteenkiste, Lens, & Deci, 2006). Mathematics perceived as a set of problems for a group solution, creating space for individual life experiences and meeting the needs of each participant becomes an object close to the students, giving them satisfaction in such a specific time as the COVID-19 pandemic rather than intensifying stress and anxiety (Ashcraft & Moore, 2009).

The project method in terms of the student/group/class activities - with a significant reduction in the teacher's activities and somewhat consultative nature of their presence, appreciates the autonomy of each student and creates a framework for co-deciding on their learning process. It can be assumed, according to the SDT evidence (Deci & Ryan, 2000), that such a strategy has a positive effect on the development of intrinsic motivation to learn and gives the students a strong belief in the practical value of acquired knowledge. By enabling the students to identify with their environment and addressing issues requiring solutions from the usability and curiosity perspective, the projects mould an active and critical event participant who feels competent in explaining and exploring his/her experiences (Bolt & Hobbs, 1989).

Moreover, increasing the student participation in the mutual explanation and interpretation of new issues to each other, treated as problems to be solved, should optimise the learning process not only in the specific time of the COVID-19 pandemic. This form of education promotes universal skills resources outside schools, such as teamwork, teamwork, effective use of new technologies, communication skills, and time management (Fernández Martín, 2020).

9. Limitations and further research

The uniqueness of the time of the study during the COVID-19 pandemic isolation limits the possibility of generating general conclusions about the similar effectiveness of cooperative mathematics teaching and learning in standard conditions. There could be likely that social deprivation associated with the quarantine period of the COVID-19 pandemic activated inclination to joint learning of the students, which in the conditions of the standard class might not be pronounced so clearly.

The study was conducted using a pilot version of the DLC-21 measures. Although its psychometric indicators appeared to be high, it requires further standardisation and a detailed assessment of psychometric properties.

Considering the potential risk of forced distance teaching in the future, it is worth including the method of e-cooperative learning in the process of standard education.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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