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ORIGINAL

MATHEMATICAL COMPETENCE DEVELOPMENT IN PRIMARY SCHOOL PHYSICAL EDUCATION CONTEXTS

DESEMPEÑO DE COMPETENCIA MATEMÁTICA EN CONTEXTOS DE LA EDUCACIÓN FÍSICA EN PRIMARIA

Rodríguez-Martín, B.¹; Buscà Donet, F.²

¹ Associate Lecturer. University of Barcelona (Spain). bea.rodriquez@ub.edu

² Director of the Applied Didactics Department. University of Barcelona (Spain).
fbusca@ub.edu

Spanish-English translator: Rocío Domínguez Castells,
rociodominguezcastells@gmail.com

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ABSTRACT

The aim of the present research was to determine to what extent the teaching resource designed in the context of Physical Education in 4th grade fostered mathematical competence development in the students. For the didactic intervention, a program was designed that presented the students with contextualized problem situations in Physical Education environments. Sixty-eight students were asked to design and implement a plan to solve the proposed situations using their mathematical knowledge and working cooperatively. A case study was designed, yielding quantitative-qualitative results. Data were collected through participant observation, field notes, questionnaires and interviews. The results showed that the students applied competence mathematical skills at medium-to-high performance levels. This learning evidence was supported by the fact that the students recognised the mathematical contents learnt and the role of mathematics in Physical Education. In addition, the mathematics teachers observed good command of content that had not been addressed in class.

KEYWORDS: Physical Education, mathematical competence, problem-based learning, situated learning.

RESUMEN

El objetivo de la investigación fue valorar en qué grado el recurso didáctico diseñado en el marco de la Educación Física de 4^o de Primaria impulsaba el desempeño de la Competencia Matemática. La intervención didáctica estaba conformada por situaciones-problema contextualizadas en entornos de Educación Física. 68 estudiantes, a través del trabajo cooperativo tenían el reto de elaborar e implementar un plan en el que utilizando sus conocimientos matemáticos resolvieran las situaciones planteadas. Se diseñó un estudio de casos cuyos resultados fueron de naturaleza cuantitativa-cualitativa. Se recogieron datos mediante la observación participante, notas de campo, cuestionarios y entrevistas. Los resultados mostraron que el alumnado ejecutó habilidades matemáticas competenciales en niveles de desempeño medio-alto. Refuerzan estas evidencias de aprendizaje que el alumnado reconociera los contenidos matemáticos aprendidos y el papel de las matemáticas en la Educación Física. Además, el profesorado de matemáticas observó un dominio de contenidos no trabajados en el aula.

PALABRAS CLAVE: Educación Física, Competencia Matemática, Aprendizaje basado en Problemas, Aprendizaje Situado.

INTRODUCTION

Changes occurred in education systems worldwide have transformed pedagogical approaches at school. Competence approach requires the implementation of an interdisciplinary, holistic, and transversal curricular model (Escamilla, 2008; Organic Law 2/2006; Organisation for Economic Cooperation and Development [in Spanish, OCDE], 2002; Zabala & Arnau, 2007). It is understandable to think that the new paradigm would modify Physical Education (PE) teaching approach. In contrast to an approach limited to a physical-sport perspective of this subject, nowadays, motor practice contexts are designed and presented as a significant means for teaching and learning key competences in modern school (Blázquez & Sebastiani, 2009; Buscà, et al., 2016; Escamilla, 2008; Perrenoud, 2006). In this regard, we deem it necessary to make the rest of subjects aware of the teaching potential of PE environments, with the purpose to use them to develop key competences from a fun, situated, multi-experience and game-based reality, close to students' interests. The present study will address the mathematics field.

Mathematical literacy is promoted in developed societies with the aim to provide students with fundamental mathematical knowledge that will allow them to act as informed, responsible, active and critical citizens. To achieve this educational requirement, a major goal of the 21st-century school is to develop students' Mathematical Competence (MaC) (NCTM, 2000; OCDE, 2003). MaC is the ability to use mathematical knowledge in a real context with the aim to solve problems (Callís, 2015; Goñi, 2008). To develop this purpose, PISA/OCDE defined various methodological guidelines divided based on: curricular contents, their context of use, MaC dimensions, the mathematisation process that determines MaC development, evaluation and methodology (Rico, 2006). Figure 1 shows a summary for primary school that was designed based on several theoretical models referenced in the present study.

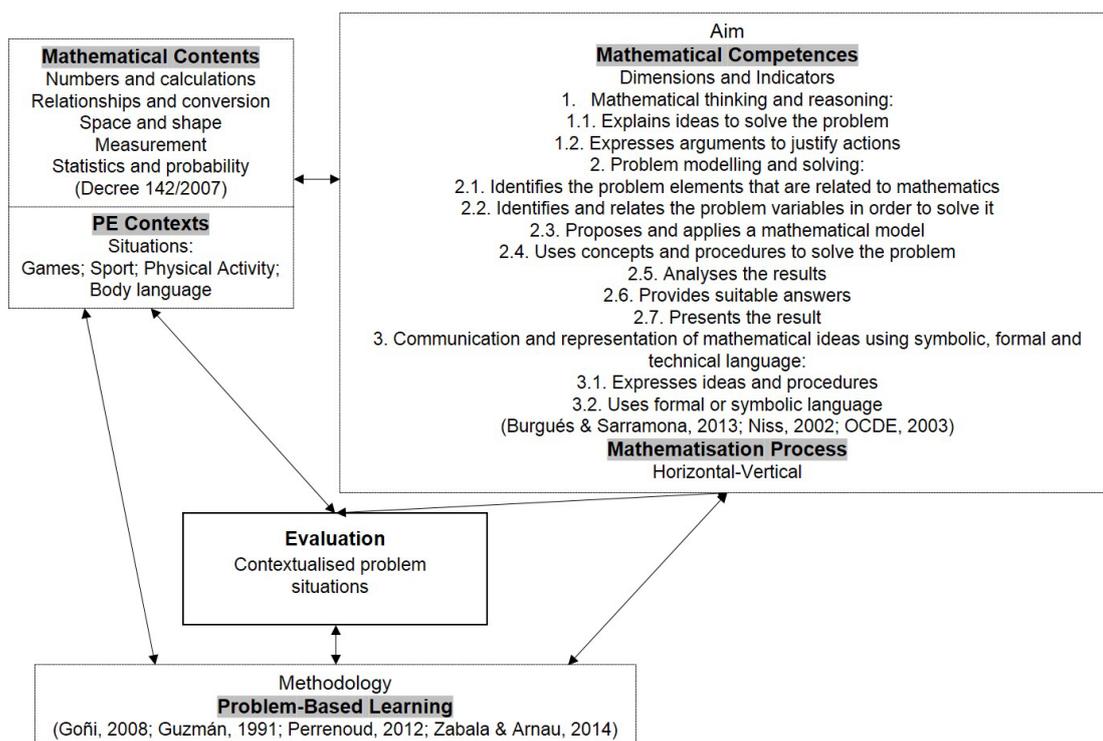


Figure 1. Didactic structure of the present study.

The use of problem situations (PS) fosters problem-based learning, which is an appropriate strategy to promote all phases of the mathematisation process and, therefore, to develop MaC (OCDE, 2003; Rico, 2005).

Nevertheless, MaC development entails various educational concerns, such as the difficulties that students encounter when trying to effectively apply their mathematical knowledge to real-life problems (Cockcroft, 1985; Evans, 1999; Guzmán, 2007; OCDE, 2003). It must also be born in mind that this subject has historically generated negative emotions in some students, such as rejection, block, insecurity or frustration (Guzmán, 2007; Lapierre & Aucouturier, 1977). Moreover, mathematics teaching needs to be updated, which is mechanical, contrived and restricted to the classroom, and to move to more applicative and situated teaching (Alsina, 2008; Blum & Niss, 1991; Cockcroft, 1985; Evans, 1999). In this regard, the results of the present research could motivate teachers to conduct innovative interdisciplinary projects in order to promote MaC development using real, applied, situated, playing PE contexts.

Previous studies have confirmed the relationship between PE and MaC, highlighting the subject's instructional value (Contreras & Cuevas, 2011; Díaz-Barahona, 2009; Escamilla, 2008; Lleixà, 2007; Rodríguez-Martín & Buscà, 2020). Nonetheless, as regards the historical relationship between PE and Mathematics at school, we can say that they have been rarely developed at an interdisciplinary level, despite their significant functional, applicative and practical bond.

At this point, the pedagogical relationship between PE and Mathematics can be defined to justify a combined approach, as shown in Figure 2. This approach considers PE as a generator of potentially significant contexts where MaC can be developed. That is, it can provide mathematisable, game-based, motor environments, situations and problems that can drive the mathematisation process forward (Rodríguez-Martín & Buscà, 2020). This process is deemed essential in order to acquire MaC (OCDE, 2003).

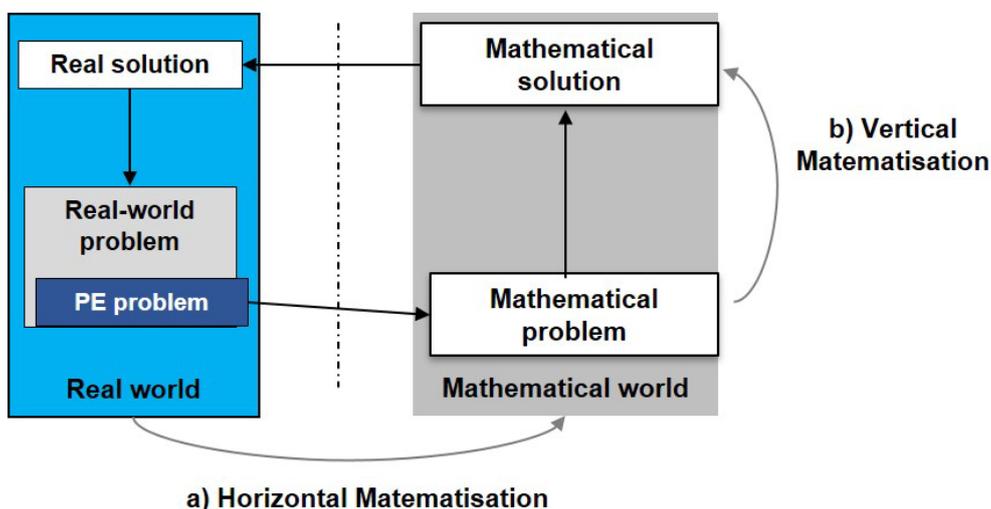


Figure 2. Didactic bond between PE and MaC (Rodríguez-Martín & Buscà, 2015).

Callís (2015) stated that experiencing and manipulation phases are paramount to access higher levels of mathematical knowledge, such as symbolisation, abstraction and generalisation. In this regard, the practical, experienced and manipulative implementation of the curricular mathematical content in PE environments occurs in situations that are real to the student, situated and contextualised in motor activities (Rodríguez-Martín & Buscà, 2020).

This idea is supported by socio-constructivist theories (Lapierre & Aucouturier, 1974; Piaget, 1978) and, more recently, by neuroscientific proposals (García-Guerrero, 2017; Gardner, 1995) that acknowledge psychomotor experience, game-based motor practice or bodily-kinesthetic intelligence as means to build structures of abstract mathematical thought upon perceptible mathematical elements. Furthermore, according to neuroscience, playing actions include interaction and game, which add the essential elements to the learning process: joy, trust, surprise, emotion, pleasure, reward and cooperation (Bueno, 2017; Forés & Ligoiz, 2009; Mora, 2013). These aspects make the curricular approach that suggests combining theory and practice effective.

The benefits of applying motor activity to mathematical learning have been recognised in theory and supported by a considerable sample of practical examples at different educational levels (Carbó, 2004; García-Guerrero, 2017; Gardner, 1998; Fernández-Díez & Arias, 2013; Hatch & Smith, 2004; Martínez de Haro & Mascaraque, 1986; Nilges & Usnick, 2000; Ortega-Del Rincón, 2005; Serrano, et al., 2008; Wade, 2016). However, there is lack of studies that show

students' MaC development when learning mathematics in contextualised PE situations.

Given the need for increasing the number of studies addressing the meaningfulness of learning mathematical content through PE, the aims of the present research were to determine to what extent the teaching resource designed within year-4 PE fostered MaC learning and development, and to assess the perception of the students and the mathematics teachers involved.

METHOD

PARTICIPANTS

A total of 68 students ($M=8.76$; $SD=0.42$) with homogeneous profile from three year-4 classes participated in the present study. The three mathematics teachers ($M=39.6$; $SD=11.0$) of these classes also collaborated in the study. The participants attended the semi-private girls' school Pineda in Hospitalet de Llobregat (Barcelona). Participants belonged to middle socioeconomic class. They were selected following convenience and accessibility criteria, since the person responsible for the study was also teaching PE. The students were divided into three groups and the PE teacher was assigned by the school management team. The aim was to conduct the study on natural, untouched groups. The mathematics teachers were selected with the aim to assess the students' perception.

PROCEDURE

Case study research methodology was chosen since the research context depended on the characteristics of a changing environment and of the participants involved (Flick, 2006; Hopkins, 1989; Stake, 1998; Yin, 2014). Table 1 shows the main characteristics of the study cases. First, approval was obtained from the ethics committee of the first author's university. Subsequently, the project was explained to the management team of the school chosen to conduct the study. Lastly, informed consent was collected from the parents or legal guardians of all students participating in the research.

Table 1. Case characteristics

	Case 1		Case 2		Case 3	
Class	4-A		4-B		4-C	
Students	19		26		23	
Mathematics teachers	1		1		1	
^a PS	PS2	PS3	PS1	PS2	PS2	PS4
Total nr. of sessions	7	5	5	8	9	5
Playing sessions	3	2	1	4	3	3

^a Four PS were analysed, two per class, due to the quality of the information collected.

The teacher-researcher filmed the intervention sessions in order to analyse them later and to collect field notes (grading rubrics) regarding the mathematical development observed during the PS solving process. The students filled in a questionnaire before and after the intervention. After every problem situation they were also requested to answer several open questions in informal group interviews. Once the intervention was completed, the mathematics teachers were asked to answer a few questions in a semi-structured interview.

INTERVENTION PROGRAMME

The intervention programme, called ‘Acti-Mates’, was implemented in three year-4 classes as an annual school project. The project plan and implementation were entirely conducted by the PE department. The educational aim of ‘Acti-Mates’ project was to develop MaC skills through cooperative solving of PS generated and presented within PE contexts.

The teaching resource consisted of four PS designed based on the process a competent action must follow (Zabala & Arnau, 2007) and the process a working group must follow to solve a mathematical problem (Guzmán, 1991). The Figure 3 shows the structure of the SP.

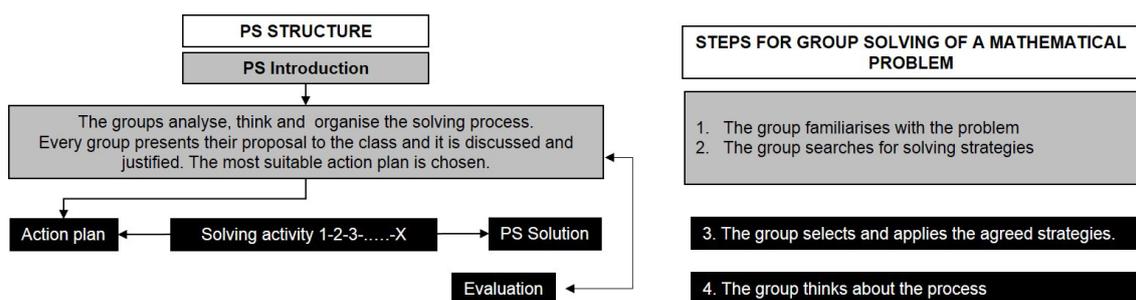


Figure 3. Structure of the S-P. Adapted from the *steps for solving a mathematical problem in a group*, Guzmán (1991)

The PS were conducted in a consecutive manner, and they were related with PE teaching units. This approach intended to increase the functional and applicative perception of PE contents, which would be transferred to the proposed PS, as well as of mathematical contents, which would have to be used according to the intrinsic need generated during the solving process.

The PS were introduced to the students contextualised in a PE environment and with the challenge to be solved in a group. The topics were: ‘Treasure Hunt’ (PS1), to design and play an orienteering game; ‘Game Creators’ (PS2), to outline a hopscotch court in the schoolyard and to invent new games; ‘We are jugglers’ (PS3), to make balls and learn how to throw them; and ‘Athletic Events’ (PS4), to organise and evaluate these events.

INSTRUMENTS

Participant observation was chosen as data collection strategy because it allows for application of several techniques and instruments (Flick, 2006). Four

were applied: 1) informal interviews to students (IS): two open questions were asked after every PS to collect qualitative information about their experience and the potential impact on their learning process: a) What did you like most about the project?; b) What do you think you have learnt?. 2) A questionnaire was administered to students before (QB) and after the intervention (QA). This allowed for assessment of their change of mind regarding the use of mathematical contents in PE. The participants answered on paper using a 4-point scale: never, rarely, often and always. Before answering, anonymity and confidentiality was guaranteed, and students were encouraged to reply honestly, since this would not affect their subject grades. 3) Field notes were taken after the intervention and recorded in grading rubrics (R) to categorise the actions performed by the students during the PS solving process. And 4) semi-structured interviews to the mathematics teachers (IT) provided information on the use of mathematical content by the students, who showed better command than in class, and on their attitude change.

DATA ANALYSIS

The information gathered in all three cases was organised and analysed at three levels: first, MaC development level; second, students' perception of their learning and the use of mathematics in PE; and third, teachers' perception of the effects of 'Acti-Mates' project on students.

The result analysis was based on text data, used to conduct inferential analysis and analytic induction (Patton, 1990). Data treatment was organised in three steps. First, reduction and categorisation of descriptive data regarding the information unit: development level in competence mathematical skills that were taken from Burgués and Sarramona (2013), Niss (2002) and OCDE (2003) and adapted to primary school. Second, interpretation of qualitative data obtained from the questionnaires through a comparison matrix containing the initial and final questionnaire results. And third, selection and interpretation of relevant quotes. Table 2 shows the relationships among variables, levels of analysis, indicators, instruments and analysis process followed.

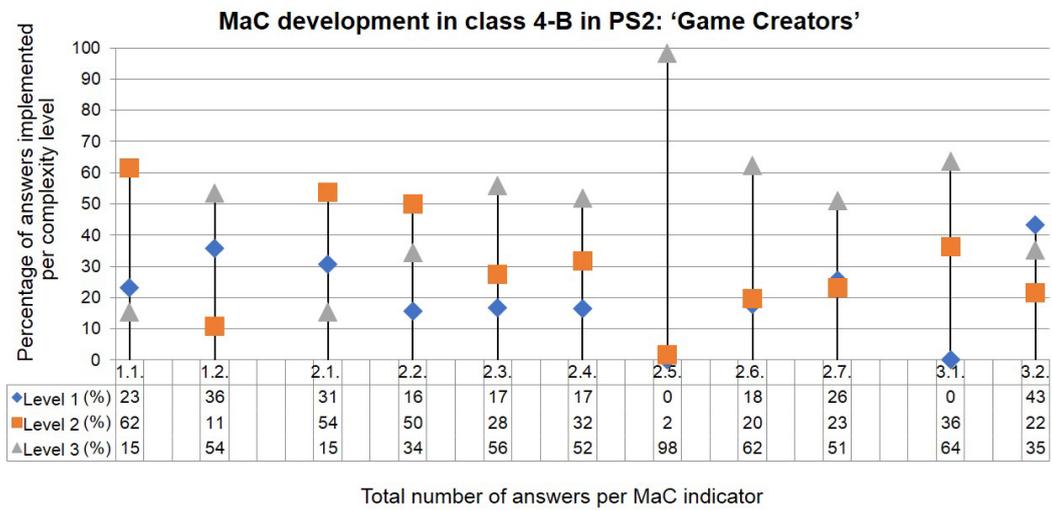
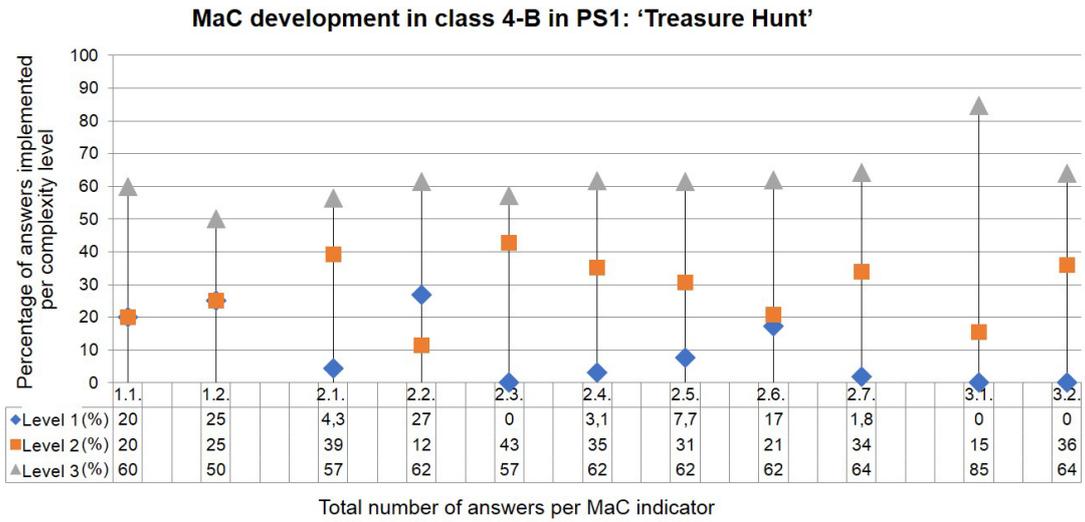
Table 2. Relationships among variables, levels of analysis, indicators, instruments and analysis process.

Variables	Indicators	Instruments	Analysis Process
Levels of analysis			
MaC development level	Competence mathematical skills	R	Reduction; Categorisation; Inferential analysis
Students' perception	Learning of mathematical contents	IS	Quote selection and interpretation
	Use of mathematics in PE	QB-QA	Inferential analysis
Mathematics teachers' perception	Effects of 'Acti-Mates' project on the students	IT	Quote selection and interpretation

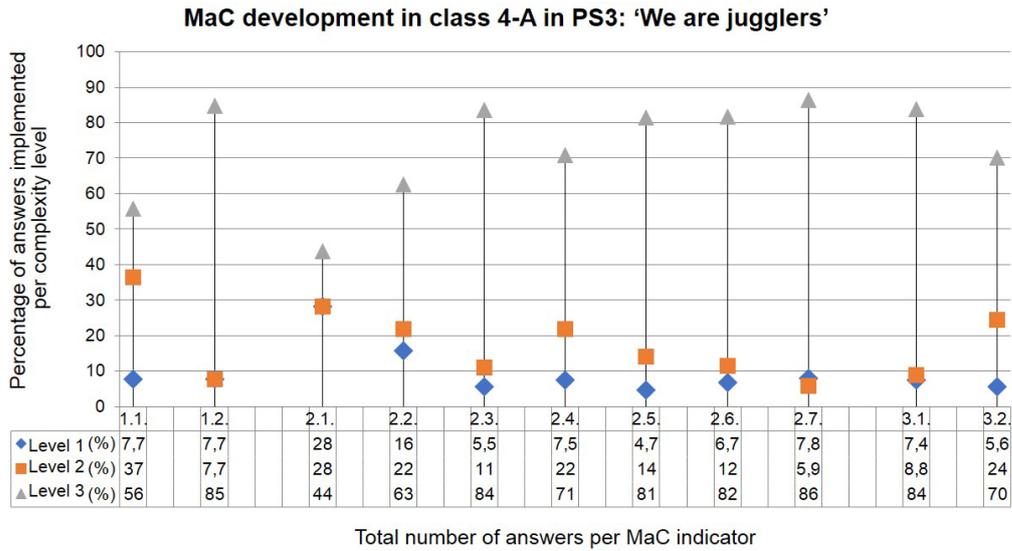
RESULTS

To what extent was the MaC developed?

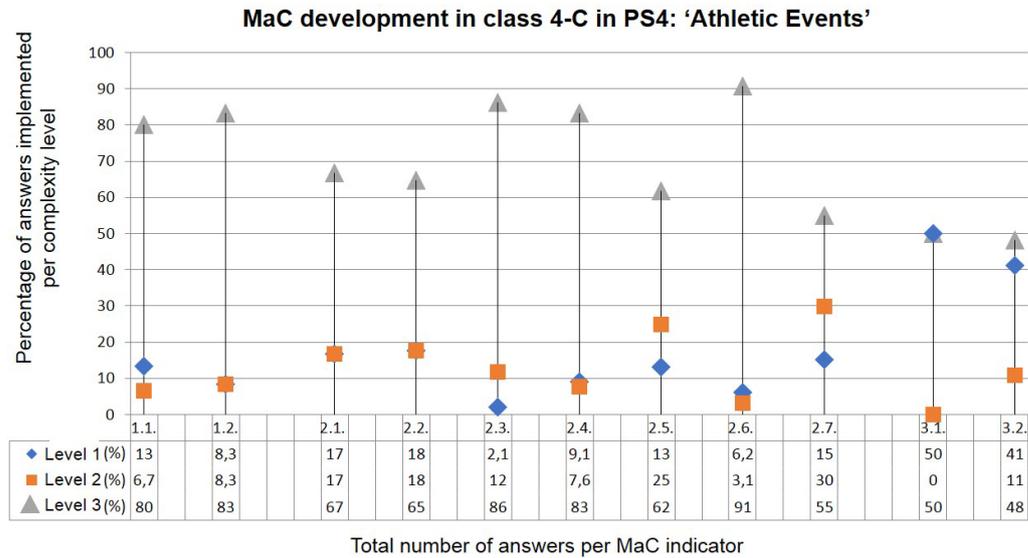
The results of the grading rubrics, shown in Figures 4, 5, 6 and 7, reveal the percentage of answers for which the students applied medium or highly-complex competence mathematical skills during PS solving. This is, their actions were correctly and effectively performed (orange square and gray triangle). Furthermore, this was observed in the vast majority of MaC dimension descriptors and in all the PS of the intervention.



Figures 4 and 5. MaC development in class 4-B in PS1 and PS2



Figures 6. MaC development in class 4-A in PS3



Figures 7. MaC development in class 4-C in PS4

What was the students' perception of mathematics learning within PE contexts?

The meta-analysis conducted by the students during the interviews revealed that they were able to reflect, identify, remember, evoke, communicate and transfer the mathematical contents they had worked on and, according to their perception, had learnt.

I learnt how to use a map. I have learnt how to orient myself and to follow coordinates (Case 2. IS_PS1).

I have played Treasure Hunt with my family. I drew a map of the house and I marked the spots where I had hidden presents (Case 3. IS_PS1).

I learnt how to measure squares, to draw a sketch, to measure without errors and to do difficult calculations (Case 2. IS_PS2).

I learnt how to use the scales and to throw the balls describing a diagonal line (Case 1. IS_PS3).

I learnt how to use a stopwatch, a measuring tape and to divide the court into 4 identical parts (Case 3. IS_PS4).

Thanks to the project I have realised that, at the beginning, I thought mathematics and PE had nothing to do with each other, but now I have seen they actually do (Case 1. IS_PS4).

In light of the questionnaire results (Figure 8), we can say that the initial questionnaire allowed for assessment of students' perception of the use of mathematical contents in PE. The data showed that, before the intervention, 33.3% of the students believed that mathematics were never applied in sport, games or PE activities and 40.9% considered they were rarely used. These data revealed that a high percentage of students did not identify any connection between the two fields. Nonetheless, the analysis of the final questionnaire shows a significant opinion change towards the perception of functional bonds between the subjects. In fact, 65.6% and 29.6% answered that mathematics were often and always used in PE, respectively.

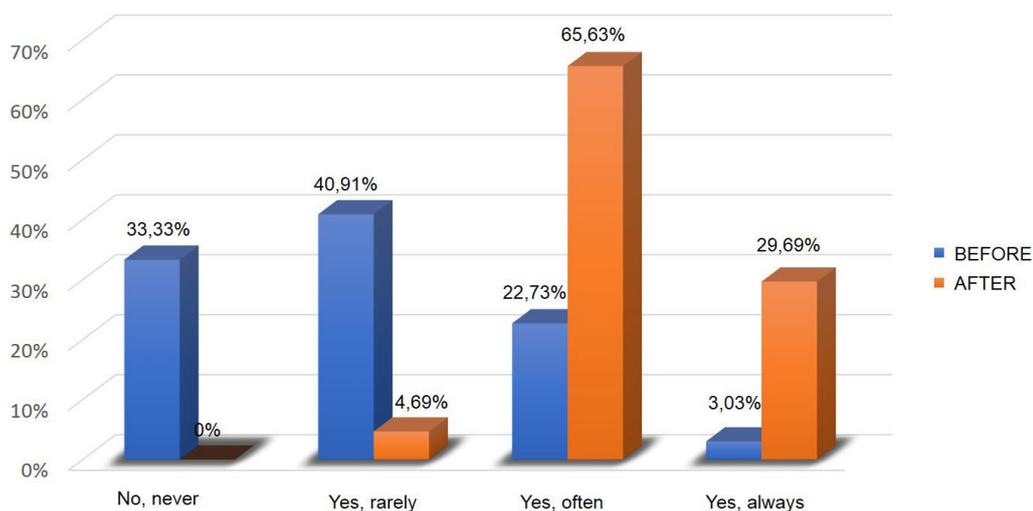


Figure 8. Initial and final questionnaire results

What was the mathematics teachers' opinion on the learning acquired through 'Acti-Mates' project?

With the aim to support the data obtained from the grading rubrics and to confirm the students' learning, the mathematics teachers reported their perception based on three facts:

1) During the mathematics lessons, the students showed better command of contents related to measurements than expected.

Measurements. As regards length, they could skilfully use the measuring tape and the ruler (Case 1. IT).

They seemed more skilled when using the measuring tape (Case 2. IT).

I noticed quite a good command of measurements (Case 3. IT).

2) The students showed good command of group problem solving strategies. They analysed the problem variables and understood the relevant mathematical elements unexpectedly well.

I have noticed that it helped them work in a cooperative manner, they went straight to the point, they learnt the content faster. I have noticed it in their time management and in the effectiveness to find the final solution (Case 3. IT).

3) A more open and positive attitude was perceived in the students when they faced the learning of new contents.

When a new topic is introduced they usually have a blocking attitude: 'we will never work it out, it is difficult, I won't be able to do it'. They always say 'no' to the new. However, we have worked on measurements and mass units at the end of the school year, they had also worked on it through 'Acti-Mates' and, despite not expressing it verbally, they showed better attitude towards learning, they were more open, less blocked (Case 1. IT).

DISCUSSION

The aims of this study were to determine to what extent the teaching resource designed within year-4 PE context fostered the acquisition and development of MaC, and to examine the involved students and mathematics teachers' opinions. The results confirmed that this methodological approach led to medium-to-high competence mathematical skill performance level during 'Acti-Mates' project PS solving. The results obtained from the students' perception of their learning were very positive. In fact, in all PS the students were able to recognise the mathematical contents involved, to verbalise those they considered to have learnt and they reported having applied the mathematical knowledge addressed in the project in their daily life. Furthermore, they were able to understand the role of mathematics in the different PE environments,

since after the intervention, the vast majority of the students acknowledged that mathematics were often or always used in PE. In addition, the mathematics teachers perceived certain command by the students of mathematical contents related with measurements that had not been addressed in class, but had been used in the different PS. Besides, they also detected an attitude change among the students, who faced more positively new contents related to measurements, space or shape used in 'Acti-Mates' project.

The results suggest that solving PS that were contextualised and situated in PE environments required the students to apply competence mathematical skills of which they could show their command in order to solve them successfully. This complexity level is considered optimal by PISA when testing this competence (OCDE, 2003; Rico, 2006). Therefore, it is believed that the students managed to use and learn MaC appropriately and efficiently through problems that were situated and contextualised in PE environments.

Among the factors that seem to indicate knowledge acquisition, Pozo (2008) considered it essential that students, as observed in our study, were able to reflect, identify, remember, evoke and communicate the contents addressed and learnt during the teaching-learning process. In line with this, several authors believe that recalling and transferring mathematical contents to new situations indicates that knowledge has been acquired. Thus, students would evoke and apply competence mathematical skills to other contexts of their daily life; in this case, to playing during their leisure time or to mathematical tasks in mathematics subject (Alsina, 2004; Evans, 1999; Freudenthal, 1993; Gallego, 2008; Goñi, 2008; Lave, 1996; Pozo, 2008; Rico, 2006).

On the other hand, in keeping with Edo (2004), English (2010, 2015), Carbó (2004), Cobb et al. (1991; 1995; 2000) o Wood et al. (1990), we understand that the fact of sharing mathematical concepts and knowledge while discussing the problem solving processes helped students improve their perception and analysis of the problem variables. It also helped them reflect on and justify the most suitable procedures for the solving process.

Furthermore, the motor activity could have provided students with symbolic conceptual meaning of the mathematical content addressed orally and in an abstract manner in class. In fact, thanks to these motor resources and through experience, analysis and observation, students were able to gather meaningful information and to understand contents related with space, time, geometry, measurements, calculations or statistics (Fernández-Díez & Arias, 2013; Martínez de Haro & Mascaraque, 1986; Rodríguez-Martín & Buscà 2020). A differentiating aspect of our study was that, like in Lampert's (1990) research and in the theoretical fundamentals of Realistic Mathematics Education (Van Reeuwijk, 1997), the results suggest that, during the teaching intervention based on game, physical activity or sport PS, students managed to perceive and understand the relevant role of mathematics in different PE learning environments. Therefore, following Rodríguez-Martín and Buscà's (2020) proposal, we could confirm that students developed their MaC during PE subject.

Historically, mathematics have had a negative emotional effect on students, causing rejection, block, insecurity or frustration (Guzmán, 2007; Lapierre & Aucouturier, 1977). By contrast, playing, experience, motor and cooperative contexts, like the ones designed in our intervention, may generate positive emotions during mathematics learning and may constitute a relaxed environment that can help overcome psychopathy caused by the subject (Alsina, 2004; Goñi, 2009; Guzmán, 2007; Van Reeuwijk, 1997).

All the above aspects reveal that, in agreement with previous practical teaching proposals (Contreras & Cuevas, 2011; Díaz-Barahona, 2009; Escamilla, 2008; Gómez-Rijo, et al., 2008; Ortega-Del Rincón, 2005) and the results of previous studies (Rodríguez-Martín & Buscà, 2020), PE contexts can contribute very significantly to students' MaC development.

CONCLUSIONS

To conclude, the relevance of this study lies in the fact that it allows us to propose game-based motor PS that are contextualised in PE environments and solved in a cooperative manner as a potentially significant resource to promote MaC learning and development at medium-to-high levels. Simultaneously, they could help reduce students' anxiety when facing certain new mathematical contents in class.

These results could, on one hand, encourage teachers of both subjects (PE and mathematics) to conduct interdisciplinary projects that promote MaC development within real, social, fun, creative, motivating, self-regulated, motor contexts. And, on the other, they could motivate mathematics teachers to use physical-motor activities as an additional teaching tool in their subject. In both cases, as in 'Acti-Mates' project, the aim would be to foster conscious mathematical literacy among students, as requested by education institutions.

This research presented the limitations of a situational study. Consequently, it would be interesting to continue investigating on these results in other schools or education stages.

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