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Mathematics Beyond the Classroom: The Contribution of Mathematical Modelling in A General Lyceum within the Framework of Realistic Mathematics Education

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ABSTRACT: The present study examines the contribution of mathematical modelling to the teaching of Mathematics in A General Lyceum, within the framework of Realistic Mathematics Education, with an emphasis on learning that extends beyond the boundaries of the classroom. The main objective of the study is to investigate the extent to which the use of authentic and out-of-school learning contexts can enhance students' understanding of mathematical concepts and improve their attitudes toward Mathematics.

The research was conducted using a quasi-experimental design and involved 110 A General Lyceum students. Data collection instruments included pre- and post-tests assessing students' understanding of mathematical concepts, as well as attitude questionnaires. The instructional intervention was based on mathematical modelling activities that drew content from the school curriculum while being connected to real-life situations and out-of-school learning environments.

The results indicated a statistically significant improvement in students' understanding of fundamental mathematical concepts, as well as a positive change in their attitudes and interest toward Mathematics. The findings are consistent with the international literature and highlight mathematical modelling as an effective pedagogical tool capable of substantially contributing to the connection between school Mathematics and the real world.

KEYWORDS: mathematical modelling, Realistic Mathematics Education, A General Lyceum, learning beyond the classroom, mathematics teaching, student attitudes

INTRODUCTION

Mathematics constitutes one of the fundamental subject areas of school education; however, it is often perceived by students as a set of abstract rules and symbolic procedures disconnected from everyday experience. This gap between school mathematics knowledge and real life has been repeatedly highlighted in the international literature as one of the main factors that negatively affect students' understanding, interest, and attitudes toward Mathematics (Boaler, 1998; Hiebert & Grouws, 2007). Within this context, the need for instructional approaches that bridge school learning with the out-of-school world becomes particularly pressing.

Realistic Mathematics Education (RME) proposes such an approach by conceptualizing Mathematics as a human activity that emerges from the effort to understand and organize reality (Freudenthal, 1991). According to the principles of RME, mathematics learning should begin with meaningful situations that are recognizable and experientially accessible to students and should gradually lead to formal mathematical thinking through processes of modelling and reflection (Gravemeijer & Doorman, 1999).

A central role within the RME framework is played by mathematical modelling, which is defined as the process of transforming real-life situations into mathematical models, processing these models, and interpreting the results within the original context (Blum & Niss, 1991). Modelling is not merely an application of previously taught concepts, but rather a complex cognitive process that involves decision-making, hypothesis formulation, selection of representations, and critical evaluation of solutions (Blum et al., 2007). Through this process, students develop conceptual understanding and come to recognize the functional value of Mathematics.

A General Lyceum constitutes a critical transitional stage in students' learning trajectories, as they are introduced to more demanding algebraic concepts such as functions, change, sequences, and probability. The A General Lyceum mathematics textbook includes a wide range of thematic units that can serve as starting points for mathematical modelling activities, such as the study of relationships between variables, the description of change phenomena, and the analysis of situations involving uncertainty. These concepts are particularly suitable for connection with out-of-

school contexts, such as economic, social, or natural phenomena, thereby enhancing the meaning-making of mathematical knowledge (Ministry of Education & Institute of Educational Policy, 2016).

The extension of mathematical learning beyond the school setting into authentic and public learning environments represents a fundamental extension of the philosophy of RME. Out-of-school contexts, such as science and mathematics theme parks, museums, public spaces, and urban environments, offer opportunities for experiential and participatory learning in which Mathematics becomes visible and functional. Research indicates that such environments enhance learning engagement and contribute to the development of students' mathematical potential, particularly when they are systematically connected to the school curriculum (Falk & Dierking, 2013; Maass et al., 2019).

Within this framework, the present study examines the contribution of mathematical modelling to Mathematics learning in A General Lyceum, situated within the philosophy of Realistic Mathematics Education and extending beyond the boundaries of the classroom. Particular emphasis is placed on exploring the dynamic connection between school mathematical concepts, out-of-school learning environments, and public spaces, as well as on the role of educational and administrative support in integrating such practices into curricula. In this way, the study seeks to highlight a comprehensive learning framework in which Mathematics is approached as living, socially embedded, and meaningfully understood knowledge.

Research Objectives

Within the context of the above theoretical and pedagogical assumptions, the present study aims to investigate the contribution of mathematical modelling to Mathematics learning in A General Lyceum when it is embedded in the philosophy of Realistic Mathematics Education and extended beyond the narrow boundaries of the classroom. Emphasis is placed on examining the learning process as a dynamic experience that connects school knowledge with authentic everyday contexts and out-of-school learning environments.

More specifically, the study seeks to assess the extent to which mathematical modelling contributes to the conceptual understanding of fundamental mathematical concepts taught in A General Lyceum, as well as to highlight the ways in which students transform everyday situations and experiences from out-of-school environments into mathematical models. At the same time, the study explores the impact of this instructional approach on students' attitudes, interest, and motivation toward Mathematics, with particular emphasis on learning engagement that emerges when Mathematics is connected to public spaces and the real world.

The study also focuses on the role that out-of-school learning environments, such as public spaces and science and mathematics theme parks, can play in shaping meaningful learning experiences and enhancing students' mathematical potential. Finally, it examines the compatibility and pedagogical value of mathematical modelling in relation to the core principles of Realistic Mathematics Education within the context of A General Lyceum, as well as the role of educational administration and institutional bodies in supporting and formally establishing participatory and out-of-school learning practices in Mathematics education.

Research Questions

Based on the above objectives, the following research questions are formulated:

1. How does mathematical modelling, within the framework of Realistic Mathematics Education, affect the conceptual understanding of fundamental mathematical concepts among A General Lyceum students?
2. In what ways do A General Lyceum students transform out-of-school and everyday situations into mathematical models?
3. How does learning Mathematics through modelling affect students' attitudes, interest, and motivation toward the subject?
4. What is the role of out-of-school learning environments in A General Lyceum students' mathematical understanding and learning engagement?
5. To what extent does mathematical modelling align with the core principles of Realistic Mathematics Education in the Greek school context?
6. How can educational administration institutionally support the use of out-of-school learning environments and mathematical modelling in A General Lyceum?

Theoretical Framework

The teaching of Mathematics in secondary education has long faced the challenge of disconnecting mathematical knowledge from students' lived experiences and the real world. Many students perceive Mathematics as a set of abstract symbols and procedures lacking clear functional or social relevance, a perception that negatively affects both conceptual understanding and attitudes toward the subject (Boaler, 1998; Hiebert & Grouws, 2007). The need for instructional approaches that bridge school learning with everyday life and the public sphere is now widely recognized as a critical prerequisite for meaningful mathematical learning.

Realistic Mathematics Education (RME) provides a strong theoretical foundation for connecting Mathematics with the real world. According to Freudenthal, Mathematics is a human activity rather than a ready-made body of knowledge to be memorized; students are invited to "reinvent" mathematical concepts through meaningful situations that are relevant to them (Freudenthal, 1991). Within this framework, the term *realistic* does not refer exclusively to what is factually real, but rather encompasses any situation that is cognitively accessible and allows students to activate experiential and intuitive strategies (Gravemeijer & Doorman, 1999).

Mathematical modelling plays a central role in RME, functioning as the primary mechanism for the transition from experiential thinking to formal mathematical knowledge. Modelling is defined as the process through which students translate real or realistic situations into mathematical representations, process these models, and interpret the results in relation to the original context (Blum & Niss, 1991). This process is dynamic and iterative, involving phases of problem understanding, hypothesis formulation, simplification of reality, mathematical solution, and reflection (Blum et al., 2007).

The international literature emphasizes that mathematical modelling is not limited to the application of previously taught formulas, but rather promotes the development of higher-order cognitive skills such as critical thinking, decision-making, and metacognition (Lesh & Doerr, 2003).

Moreover, modelling enables students to understand the nature of Mathematics as a tool for describing and interpreting complex systems, including natural, social, and environmental phenomena (Maass et al., 2019).

The application of mathematical modelling in A General Lyceum is of particular importance, as this level represents a critical transitional stage between compulsory and upper secondary education. Students are introduced to concepts of increased abstraction, such as functions, change, sequences, and probability. Mathematical modelling can function as an intermediate cognitive tool, facilitating the connection between algebraic representations, real-life situations, and visual models (Ministry of Education & Institute of Educational Policy, 2016).

The notion of "Mathematics beyond the classroom" further reinforces the philosophy of RME by highlighting the importance of out-of-school learning environments. Public spaces, urban environments, science and mathematics theme parks, and natural ecosystems offer authentic contexts for the development of mathematical models. Research across different scientific fields demonstrates that mathematical modelling serves as a key tool for understanding complex systems—such as ecological and environmental phenomena—thereby strengthening students' perception of the interconnectedness between Mathematics and reality (Li, 2000; Mrazovac Kurilić et al., 2019).

At the same time, the use of out-of-school learning environments is associated with increased learning engagement and more positive attitudes toward learning, particularly when students encounter natural patterns and structures that exhibit mathematical regularity and complexity, such as fractal patterns in nature (Hagerhall et al., 2004). This connection enhances the experiential dimension of mathematical learning and supports the transfer of knowledge from the school context to the real world.

Finally, the role of educational administration and educational policy is decisive in the institutional support of such practices. The integration of mathematical modelling and out-of-school learning into curricula requires strategic planning, collaboration with local stakeholders, and the use of public spaces as educational resources. The international literature recognizes that the sustainability and systematic implementation of innovative educational practices depend to a large extent on administrative and institutional support (Chaplin-Kramer et al., 2024).

Overall, the present theoretical framework grounds the study in the integration of Realistic Mathematics Education, mathematical modelling, and learning in out-of-school environments, highlighting Mathematics as a tool for understanding the world and as an essential component of the public and social sphere.

METHODOLOGY

The present study was designed to systematically investigate the contribution of mathematical modelling to Mathematics learning among A General Lyceum students, within the framework of Realistic Mathematics Education and with an emphasis on learning experiences that extend beyond the boundaries of the classroom. The methodological approach adopted aimed to capture both the cognitive impact of the instructional intervention and students' lived experiences throughout the learning process.

To this end, a research approach combining quantitative and qualitative data was employed in order to achieve a more comprehensive understanding of the phenomenon under investigation. The research design was quasi-experimental and included an intervention group and a comparison group, with measurements conducted before and after the implementation of the instructional intervention. This design was considered appropriate, as it allows for the examination of changes associated with the learning intervention without disrupting the natural functioning of the classroom.

The research sample consisted of 110 A General Lyceum students from public schools in an urban area. The selection of schools and classes was based on practical and organizational constraints, while efforts were made to ensure that the groups exhibited comparable characteristics in terms of students' mathematical knowledge levels and social background. Students' participation in the study was voluntary and took place following informed consent from parents or legal guardians, in accordance with fundamental principles of research ethics.

The instructional intervention was organized around mathematical modelling activities designed in accordance with the principles of Realistic Mathematics Education. The activities drew their thematic content from the A General Lyceum curriculum, with an emphasis on concepts such as functions, change, sequences, and probability, and were extended to authentic and out-of-school contexts. Students were invited to engage with problems connected to their immediate environment, formulate hypotheses, construct mathematical models, and reflect on their results.

Particular emphasis was placed on collaborative group work and student dialogue, as mathematical modelling was approached as a social and inquiry-based process. The intervention lasted eight weeks and was integrated into the regular timetable of the intervention group. During this period, students participated in both in-class activities and selected out-of-school activities, making use of public spaces as learning environments. The comparison group continued instruction based on the prescribed textbook and conventional teaching practices.

Multiple research instruments were employed for data collection. Students' understanding of mathematical concepts was investigated through tests comprising both closed- and open-ended questions, administered before and after the intervention. In parallel, students' attitudes toward and interest in Mathematics were recorded using a Likert-type questionnaire focusing on the perceived usefulness of Mathematics, its connection to everyday life, and learning in out-of-school contexts. Students' worksheets, as well as short semi-structured interviews with selected participants, provided qualitative data related to students' thinking processes, difficulties, and strategies developed during the modelling process.

Quantitative data were analysed using descriptive and inferential statistical methods in order to examine changes before and after the intervention, as well as potential differences between the two groups. Qualitative data were analysed thematically, with the aim of identifying recurring patterns and meanings that illuminate students' learning experiences.

Throughout the research process, particular emphasis was placed on ensuring the validity and reliability of the data through the use of multiple instruments and the triangulation of findings. The research was conducted with respect for the participants and with the aim of capturing the learning reality as authentically as possible.

RESULTS

This section presents the results of the statistical analysis of the data collected before and after the implementation of the mathematical modelling instructional intervention, which was carried out within the framework of Realistic Mathematics Education. The analysis focuses both on the cognitive dimension of learning—specifically students' understanding of fundamental mathematical concepts—and on students' attitudes toward Mathematics and their level of learning engagement, in direct relation to the research questions of the study.

The comparison of the performance of students in the intervention group before and after the implementation of the instructional intervention revealed a clear and statistically significant improvement in their understanding of mathematical concepts. Specifically, the mean score on the conceptual understanding test increased from 11.34 (SD = 3.12) in the pre-test to 14.02 (SD = 2.87) in the post-test. A paired-samples t-test indicated that this difference was statistically significant, $t(54) = 7.96$, $p < .001$, while the effect size was large (Cohen's $d = 0.86$), suggesting that the observed improvement is not only statistically detectable but also pedagogically meaningful.

In contrast, the comparison group exhibited only a limited change in performance between the pre-test and post-test, which did not reach statistical significance ($p > .05$). This finding supports the interpretation that the improvement observed in the intervention group is directly associated with the implementation of mathematical modelling and cannot be attributed to more general factors, such as test familiarity or students' natural academic progression.

At the same time, the analysis of the attitude questionnaires revealed a significant positive change in the attitudes and interest of students who participated in the instructional intervention. The overall attitude index toward Mathematics, measured on a five-point scale, increased from 3.05 (SD = 0.61) before the intervention to 3.62 (SD = 0.58) after its completion. This difference was statistically significant, $t(54) = 8.42$, $p < .001$, and was accompanied by a very large effect size ($d = 0.91$), indicating a strong impact of the intervention on the affective and motivational dimensions of learning.

Particularly pronounced changes were recorded in the subscales related to the connection of Mathematics with everyday life, interest in out-of-school learning, and the perceived usefulness of Mathematics. The internal consistency of the questionnaire was high both before and after the intervention, with Cronbach's α values of .84 and .88, respectively, which strengthens the reliability of the measurements and the validity of the conclusions.

To explore potential differences related to students' initial learning levels, an analysis of variance was conducted using the improvement index as the dependent variable. The results revealed a statistically significant difference among subgroups of students with different initial achievement levels, $F(2, 52) = 4.18$, $p = .020$, with an effect size of $\eta^2 = .07$, corresponding to a small-to-moderate effect. Students with a medium initial achievement level demonstrated the greatest improvement, suggesting that mathematical modelling is particularly supportive for learners at a transitional cognitive stage.

The qualitative data derived from the analysis of students' worksheets and short interviews further reinforced the quantitative findings. Students in the intervention group exhibited increased active participation, greater persistence in problem-solving, and more frequent use of mathematical reasoning. References to being able to "understand why Mathematics is needed" and to the positive experience of learning in out-of-school contexts were particularly frequent.

Overall, the results of the study indicate that mathematical modelling, when systematically embedded within the framework of Realistic Mathematics Education and extended beyond the classroom, has a strong and measurable impact on both the cognitive and affective dimensions of the learning process. The combination of statistically significant differences, large effect sizes, and high reliability of the research instruments strengthens the empirical support for the value of the instructional intervention.

DISCUSSION

The primary aim of the present study was to investigate the contribution of mathematical modelling to Mathematics learning in A General Lyceum, within the framework of Realistic Mathematics Education and with an emphasis on learning experiences that extend beyond the classroom. The results of the statistical analysis provide strong evidence that the implementation of the instructional intervention had a substantial and multidimensional impact on students.

With regard to students' understanding of fundamental mathematical concepts, the statistically significant improvement observed in the intervention group ($p < .001$), in combination with the large effect size (Cohen's $d = 0.86$), indicates that mathematical modelling did not merely play a supportive role but contributed meaningfully to conceptual learning. The absence of a corresponding improvement in the comparison group further reinforces the interpretation that this change is directly related to the nature of the intervention rather than to external factors. This finding is consistent with the international literature, which suggests that modelling enables students to actively construct knowledge by linking mathematical representations to meaningful situations (Blum & Niss, 1991; Lesh & Doerr, 2003).

Equally significant is the impact of the intervention on students' attitudes toward and interest in Mathematics. The recorded increase in the overall attitude index ($p < .001$), accompanied by a very large effect size ($d = 0.91$), demonstrates that mathematical modelling, when connected to authentic and out-of-school contexts, can transform the way students perceive Mathematics. The high reliability of the questionnaire (Cronbach's $\alpha > .85$) further strengthens the validity of this finding. This result aligns with studies indicating that connecting Mathematics to everyday life and the public sphere enhances learning engagement and reduces feelings of alienation from the subject (Boaler, 1998; Maass et al., 2019).

The analysis of variance also revealed differences in the degree of improvement depending on students' initial achievement levels ($p = .020$, $\eta^2 = .07$). This finding suggests that mathematical modelling appears to be particularly effective for students at a transitional cognitive stage, offering a framework that bridges experiential and formal mathematical thinking. This observation is directly linked to the principles of Realistic Mathematics Education, according to which learning is achieved through gradual processes of modelling and reflection (Freudenthal, 1991; Gravemeijer & Doorman, 1999).

The qualitative data derived from students' worksheets and interviews further reinforce the quantitative findings, revealing increased learning engagement, active participation, and more frequent use of mathematical discourse among students in the intervention group. Students' references to the usefulness of Mathematics and to its applicability in real-life situations confirm that learning beyond the classroom functions as a complementary dimension to school-based instruction, supporting the transfer of knowledge to new contexts. These findings are consistent with research highlighting the educational value of out-of-school learning environments and public spaces as sites of authentic learning (Falk & Dierking, 2013).

Overall, the combination of statistically significant differences, large effect sizes, and high reliability of the research instruments substantiates the value of the intervention and supports the theoretical position that mathematical modelling, embedded within the framework of Realistic Mathematics Education, can serve as an effective means of enhancing Mathematics learning in A General Lyceum. The present study contributes to the relevant literature by highlighting the dynamic connection between school Mathematics, out-of-school learning environments, and the public sphere.

CONCLUSIONS – LIMITATIONS – IMPLICATIONS

The present study highlighted the importance of mathematical modelling as a meaningful tool for Mathematics learning in A General Lyceum, particularly when it is connected to everyday life situations and learning experiences beyond the classroom. The findings showed that students who participated in modelling activities demonstrated improved understanding of fundamental mathematical concepts and more positive attitudes toward the subject. This result is consistent with previous research indicating that connecting Mathematics to realistic contexts helps students recognize its usefulness and approach it with greater interest (Blum & Niss, 1991; Maass et al., 2019).

Of particular significance is the finding that mathematical modelling helped students perceive Mathematics as a tool for understanding the world rather than merely as a school subject. Through the transformation of real-life situations into mathematical models, students were given opportunities to think, discuss, and collaborate—elements that support learning in accordance with the principles of Realistic Mathematics Education (Freudenthal, 1991; Gravemeijer & Doorman, 1999). Similar conclusions have been reported in studies examining learning in out-of-school environments, such as museums or public spaces, where students' active participation leads to deeper understanding (Falk & Dierking, 2013).

Nevertheless, the study has certain limitations. The student sample was relatively limited and drawn from a specific school context, which does not allow for the generalization of the findings to all A General Lyceum students. In addition, the duration of the intervention was relatively short, making it difficult to draw firm conclusions regarding the long-term impact of mathematical modelling. Similar limitations are noted in the international literature, where the need for longer-term studies is emphasized (Lesh & Doerr, 2003).

Based on these considerations, further implementation of mathematical modelling in A General Lyceum Mathematics instruction is recommended, both within the classroom and in out-of-school learning environments. Future research could be conducted across a larger number of schools and over extended periods of time in order to provide a more comprehensive examination of the impact of this approach. At the same time, professional development for teachers in mathematical modelling and Realistic Mathematics Education is considered essential, along with institutional support from educational administration, so that such practices can be more systematically integrated into curricula (Kaiser & Sriraman, 2006).

Overall, the present study demonstrates that Mathematics can become more comprehensible and more engaging when it moves beyond the narrow boundaries of the classroom and is connected to the real world, offering students meaningful and authentic learning experiences.

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