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Mathematical modeling: a study on its incorporation into basic education from the proceedings of SIPEM[1]

Modelización matemática: un estudio de su incorporación a la enseñanza básica a partir de los anales del SIPEM

La modélisation mathématique : une étude de son intégration dans l'enseignement de base à partir des annales du SIPEM

Modelagem matemática: um estudo sobre sua incorporação na educação básica a partir dos anais do SIPEM

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Abstract

This article aims to investigate the incorporation of mathematical modeling in the mathematics teaching-learning process, specifically in the context of basic education. In this sense, based on the academic productions made between 2000 and 2021, an analysis of the proceedings published in the eight editions of the International Seminar on Research in Mathematics Education (SIPEM), one of the main events promoted by the Brazilian Society of Mathematical Education (SBEM) was carried out. With a qualitative approach, the research considered quantitative and descriptive methodological aspects. This study revealed that mathematical modeling can be seen in different contexts, both as a didactic and pedagogical proposal for organizing and guiding the teacher's work in the school environment and as a research proposal for academic research. In addition, we noted that modeling can be

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incorporated into the classroom through different everyday themes, for example, when exploring electricity consumption, water consumption, air pollution, and purchases made in a supermarket. With this, we understand that one of the potentials of modeling is to transform concrete problems from students' reality into mathematical problems. From the above discussion, we can conclude that modeling in the basic education classroom can transform this space into a learning environment contextualized with the students' reality, lively, dynamic, and investigative.

Keywords: Mathematical modeling, Teaching mathematics, Basic education, International research seminar in mathematics education.

Resumen

El objetivo de este artículo es investigar la incorporación de la modelización matemática en el proceso de enseñanza-aprendizaje de las matemáticas, más específicamente en el contexto de la educación básica. Para ello, se realizó un análisis, basado en las producciones académicas realizadas entre 2000 y 2021, de los anales publicados en las 8 ediciones del Seminario Internacional de Investigación en Educación Matemática (SIPEM), uno de los principales eventos promovidos por la Sociedad Brasileña de Educación Matemática (SBEM). La investigación cualitativa consideró aspectos metodológicos cuantitativos y descriptivos. El estudio mostró que la Modelización Matemática puede ser vista en diversos contextos, tanto como propuesta didáctica y pedagógica para organizar y orientar el trabajo de los profesores en el ambiente escolar, como propuesta de investigación para la investigación académica. Además, observamos que la modelización puede incorporarse al aula a través de diferentes temas cotidianos, por ejemplo, al explorar el consumo de electricidad, el consumo de agua, la contaminación del aire y las compras en un supermercado. Teniendo esto en cuenta, una de las potencialidades de la modelización es transformar problemas concretos de la realidad de los alumnos en problemas matemáticos. En vista de lo anterior, es posible concluir que el uso de la modelización en el aula de primaria puede transformar este espacio en un ambiente de aprendizaje contextualizado con la realidad de los alumnos, vivo, dinámico e investigativo.

Palabras clave: Modelización matemática, Enseñanza de las matemáticas, Educación básica, Seminario internacional de investigación en educación matemática.

Résumé

L'objectif de cet article est d'étudier l'incorporation de la modélisation mathématique dans le processus d'enseignement-apprentissage des mathématiques, plus particulièrement dans le

contexte de l'éducation de base. À cette fin, une analyse a été réalisée, basée sur les productions académiques réalisées entre 2000 et 2021, des annales publiées dans les 8 éditions du Séminaire international sur la recherche dans l'enseignement des mathématiques (SIPEM), l'un des principaux événements promus par la Société brésilienne de l'enseignement des mathématiques (SBEM). La recherche qualitative a pris en compte les aspects méthodologiques quantitatifs et descriptifs. L'étude a montré que la modélisation mathématique peut être considérée dans différents contextes, à la fois comme une proposition didactique et pédagogique pour organiser et guider le travail des enseignants dans l'environnement scolaire et comme une proposition de recherche pour la recherche universitaire. En outre, nous constatons que la modélisation peut être incorporée en classe par le biais de différents thèmes quotidiens, par exemple lors de l'exploration de la consommation d'électricité, de la consommation d'eau, de la pollution de l'air et des achats au supermarché. Dans cette optique, l'un des potentiels de la modélisation est de transformer des problèmes concrets de la réalité des élèves en problèmes mathématiques. Au vu de ce qui précède, il est possible de conclure que l'utilisation de la modélisation dans la classe de l'école primaire peut transformer cet espace en un environnement d'apprentissage contextualisé avec la réalité des élèves, vivant, dynamique et investigateur.

Mots-clés : Modélisation mathématique, Enseignement des mathématiques, Éducation de base, Séminaire international sur la recherche dans l'enseignement des mathématiques.

Resumo

Esse artigo tem como objetivo investigar a incorporação da Modelagem Matemática no processo de ensino-aprendizagem de Matemática, mais especificamente, no contexto da Educação Básica. Nesse sentido, foi realizada uma análise, a partir das produções acadêmicas feitas entre os anos 2000 e 2021, dos anais publicados nas 8 edições do Seminário Internacional de Pesquisa em Educação Matemática (SIPEM), um dos principais eventos promovidos pela Sociedade Brasileira de Educação Matemática (SBEM). A pesquisa, de abordagem qualitativa considerou, aspectos metodológicos quantitativos e descritivos. Diante desse estudo, observou-se que a Modelagem Matemática pode ser vista em diversos contextos, tanto como uma proposta didática e pedagógica de organização e orientação do trabalho do professor no ambiente escolar quanto como uma proposta de investigação para pesquisas acadêmicas. Além disso, notamos que a Modelagem pode ser incorporada em sala de aula, por meio de diferentes temáticas do dia a dia, por exemplo, ao explorar o consumo de energia elétrica, o consumo de água, a poluição do ar e as compras realizadas em um supermercado. Com isso, entende-se que a Modelagem tem como um de seus potenciais transformar problemas concretos da realidade

dos alunos em problemas matemáticos. Diante do exposto, é possível concluir que a utilização da Modelagem, na sala de aula da Educação Básica, pode transformar esse espaço em um ambiente de aprendizagem, contextualizado com a realidade dos alunos, vivo, dinâmico e investigativo.

Palavras-chave: Modelagem matemática, Ensino de matemática, Educação básica, Seminário internacional de pesquisa em educação matemática.

Mathematical modeling: a study on its incorporation into basic education based on the SIPEM proceedings

It is noteworthy that, over time, the mathematics teaching-learning process has been increasingly discussed and analyzed amid the improvements and challenges observed in the different stages of teaching in basic education, according to the diversity of resources that have been developed and the methodologies and strategies to transform how mathematical content is worked on in the classroom (Almeida & Dias, 2004). The need to improve this process arose when it was observed that students had difficulty learning, aligned with their tendency to remain in the traditional teaching structure, leading to a more mechanized bias in the methodological aspects guided by teachers.

In the 1930s, during the expansion of coffee culture and accelerated urbanization, a proposal called "New School" for educational change was developed (Dos Santos, Prestes, & Do Vale, 2006). This movement sought to place students at the center of the learning process. With the new-school movement, "several mathematics educators, the first and main contributors to the development of mathematics" (Almeida, 2018, p. 1-2) came to the fore, among them, Malba Tahan (who proposed a teaching that valued students' reasoning development) and Euclides Roxo (who was in favor of more intuitive teaching), who contributed significantly to changes aimed at mathematical teaching.

Given educators' opposition to "traditional" teaching, dissatisfaction with this teaching model and the desire for transformation in education only increased. Following the creation of the Ministry of Education and Culture (MEC) in 1930, debates and areas were unified; for example, arithmetic, algebra, and geometry came under the name of mathematics, as we know it today (Müller, 2000). As the decades passed, students' discontent grew. They questioned school mathematics usage in the real world, as did parents and guardians who, often wanting to help their children, could not understand the content, mainly because of the Modern Mathematics Movement. Ubiratan D'Ambrósio, an exceptional mathematical scholar, states that there is "something wrong with the mathematics we are teaching. The content we try to pass on through school systems is obsolete, uninteresting, and useless" (D'Ambrósio, 1991, p. 1, our adaptation).

Students are often unable to reflect on possible applications of the concepts taught, much less the effectiveness of the learning process, or they also use mathematical concepts and elements mechanically, without thinking about it (D'Ambrósio, 1991). However, the construction of mathematical knowledge can be much more efficient since it emerges from the place where one lives; because mathematics is in everything that surrounds individuals, from

the process of doing the monthly shopping at the supermarket to the amount of garbage produced by a population, that is, in real-life situations. Therefore, exploring and applying such real situations to teaching mathematics will possibly make student learning more dynamic and engaging. So, it is up to the teacher to be concerned, for example, with improving the teaching process to favor learning.

From this perspective, trends in mathematics education emerge as possibilities to enhance the teacher's work in the classroom. For example, the National Curriculum Parameters (Parâmetros Curriculares Nacionais - PCNs) (Brasil, 1998) indicate the use of the history of mathematics, communication technologies, and games. The National Curriculum Guidelines for Secondary Education (Orientações Curriculares Nacionais Para o Ensino Médio - OCNEM) (Brasil, 2006), in addition to these first two observed in the PCNs, also give guidance for work through mathematical modeling. The National Common Curriculum Base (Base Nacional Comum Curricular - BNCC) (Brasil, 2018), a normative document that governs basic education in contemporary times, also refers to these possibilities of exploring mathematics in the classroom, even if implicitly.

For teaching that considers something students experience –real everyday situations– we focus this study on mathematical modeling. More specifically, it consists of transforming real-world problems into mathematical problems (Almeida & Dias, 2004; Bassanezi, 2002; Biembengut, 1999). According to Bassanezi (2002), when applied to teaching, mathematical models can become an excellent way to direct students' interest and make them observe mathematics with different eyes, thus expanding their knowledge and helping structure their thinking and acting. Thus, in this context, modeling is a mathematical study that "involves the formulation of appropriate hypotheses and simplifications in the creation of mathematical models to analyze the problem under study" (Almeida & Dias, 2004, p. 3).

In recent decades, the number of research and academic productions involving the use of modeling in the context of mathematics education has been quite significant, especially when it comes to the efforts undertaken in the process of investigating the different aspects of the use of mathematical models, from their understanding and presence in the classroom to their pedagogical practice (Kato & Oliveira, 2020).

Given the context presented, in which the need for actions that prioritize students' daily practices for the classroom context was seen, and given the potential of mathematical modeling for this purpose, the question arose: What can be observed in research that has explored mathematical modeling in basic education? To answer this question, we aimed to investigate

the incorporation of mathematical modeling in the mathematics teaching-learning process, specifically in the basic education context.

To this end, based on a qualitative research approach and bibliographical research, we analyzed academic productions from 2000 through 2021 included in the proceedings published in the eight editions of SIPEM, one of the main events promoted by SBEM.

Next, the methodological elements of this study are shown, and subsequently, the results of the bibliographic research are presented. Once this is done, we discuss what the analyzed works indicate and our conclusions, which are included in the final considerations.

Methodology

Given the objective of this work, as previously stated, a bibliographic survey was conducted based mainly on a qualitative research approach with some elements of a quantitative investigation. For data collection and study development, the systematic review method was followed, which, unlike the traditional narrative review, uses explicit methods for more comprehensive bibliographic research, critically evaluating individual studies, extracting data, and synthesizing the results (Donato & Donato, 2019).

To develop the systematic review, considering Donato and Donato's (2019) perspective, we adopted the nine steps they foresee:

> 1. Formulate a research question; 2. Produce a research protocol and register it (items 1 and 3 to 8 must be included in the systematic review preparation protocol); 3. Define inclusion and exclusion criteria; 4. Develop a research strategy and search the literature – find the studies; 5. Select the studies; 6. Assess the quality of the studies; 7. Extract data; 8. Synthesize the data and assess the quality of evidence; 9. Disseminate the results – Publish them (Donato & Donato, 2019, p. 228).

Regarding the first step, as the authors suggest, the research question was developed: What can be observed in research that has explored mathematical modeling in basic education?

As for the other steps, during the study, some of the actions taken were exposed, although indirectly, but necessary for understanding the review, for example, the search terms and the criteria for including or excluding works.

As previously indicated, this research used quantitative aspects to present a general picture of the data collected to enable the reader to understand the results obtained fully. In addition to the qualitative approach to analysis, a descriptive approach is used to present the results, given that data processing requires a certain level of detailing of the characteristics of each analyzed work (Pereira, 2022). Given this methodological orientation, the academic

productions published in the proceedings of all eight editions of SIPEM, an event organized by SBEM, were analyzed.

SIPEM, in turn, has as its primary objective to promote exchange between groups from different countries in the meeting of other researchers who are dedicated to producing research in the area of mathematics education, providing the possibility of learning about the investigations that are being carried out in various institutions, in addition to bringing together Brazilian and foreign researchers. However, due to the scope of this event, we consider that the scope of this study is research involving modeling.

Besides this delimitation, the time taken was from 2000 to 2021, when all editions of SIPEM took place. As the locus of the investigation, we chose the SIPEM platform and the SBEM website. To access the desired works, we searched all its proceedings, which, as already noted, contain academic productions related to various themes regarding mathematics education. For the search, we chose the following terms (or keywords): "Modelagem Matemática"; "Ensino-Aprendizagem" and "Educação Básica" ["Mathematical Modeling"; "Teaching-Learning" and "Basic Education"].

From these descriptors, we defined the criteria for data selection. One exclusion criterion was works related to mathematical modeling focused on higher education and teacher education. Despite this, we still needed to read all abstracts that contained the keyword "Modelagem Matemática" ["mathematical modeling"] to make a more accurate verification of the educational level at which the work was addressed.

In studies where abstracts did not make it clear whether the research aimed at basic education, we read the introduction before including or excluding the text from our collection. Only then were the studies selected and subsequently analyzed.

Survey totals

Following the defined descriptors, the search on the SIPEM website was guided by the following steps: 1. Select the "Proceedings" tab in the header and then "SIPEM"; 2. Click on "Previous Editions" to access links from the first to the seventh edition of SIPEM; and 3. Click on "Current Edition" to access the most recent edition of the event, the eighth.

The tab directs to the editions, offering links to the proceedings of each edition. From the 4th SIPEM onwards, reports of each event were also made available. By analyzing the materials available on the platform, we could organize the data relating to the works published in all editions (Table 1).

Table 1.

Works published in SIPEM

Editions	WGs	Submitted papers	Published papers
1st SIPEM (2000)	9	*[5]	112
2nd SIPEM (2003)	12	162	156
3rd SIPEM (2006)	12	*	211
4th SIPEM (2009)	12	244	162
5th SIPEM (2012)	12	232	154
6th SIPEM (2015)	13	282	169
7th SIPEM (2018)	15	292	226
8th SIPEM (2021)	15	288	226
TOTAL			**964**

Table 1 shows that 964 papers were published in the SIPEM proceedings, adding up all eight editions of the event. Of this number, we found 108 productions addressing mathematical modeling. For example, in theoretical aspects, actions were aimed at teacher education, and experiences were in basic education. Forty out of these 108 works were about mathematical modeling in the context of teaching-learning in basic education, which is the focus of this study (Figure 1):

5 Information marked with * is not available on the event websites.

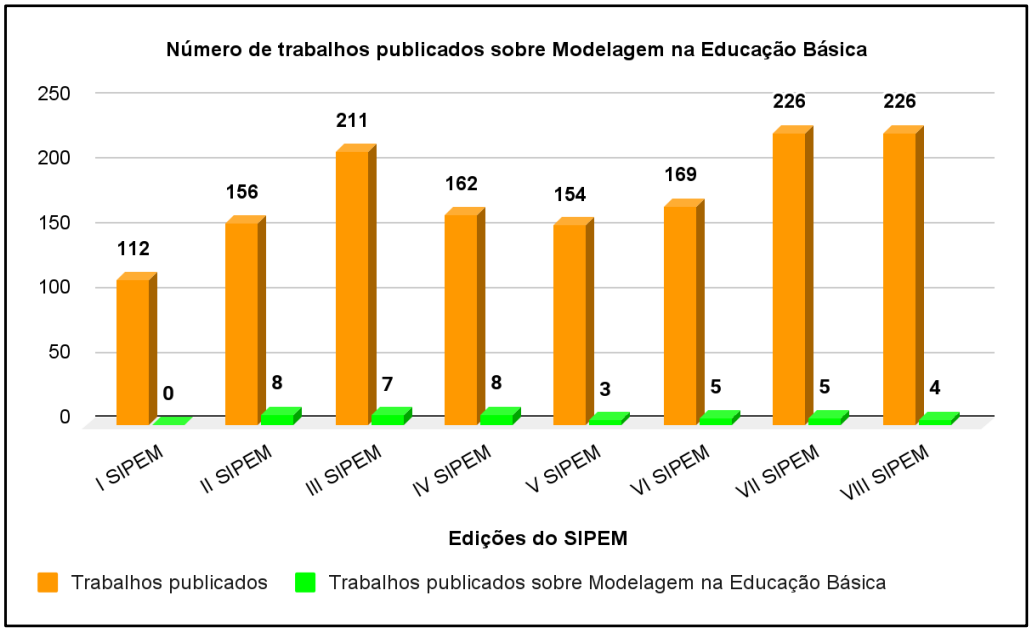

Figure 1.

Published papers on mathematical modeling in the teaching-learning process in basic education in each SIPEM edition (Own elaboration)

Figure 1 shows the distribution of productions throughout the eight editions of SIPEM, in which it is possible to verify the total number of works covering varied themes. The number of studies that addressed mathematical modeling in basic education is also highlighted. At first, considering the number of investigations in each edition, the number of works on modeling in basic education seems small; however, it was necessary to consider that SIPEM receives works for several different themes in mathematics education. Furthermore, as already highlighted, there were more papers on the topic (Figure 2).

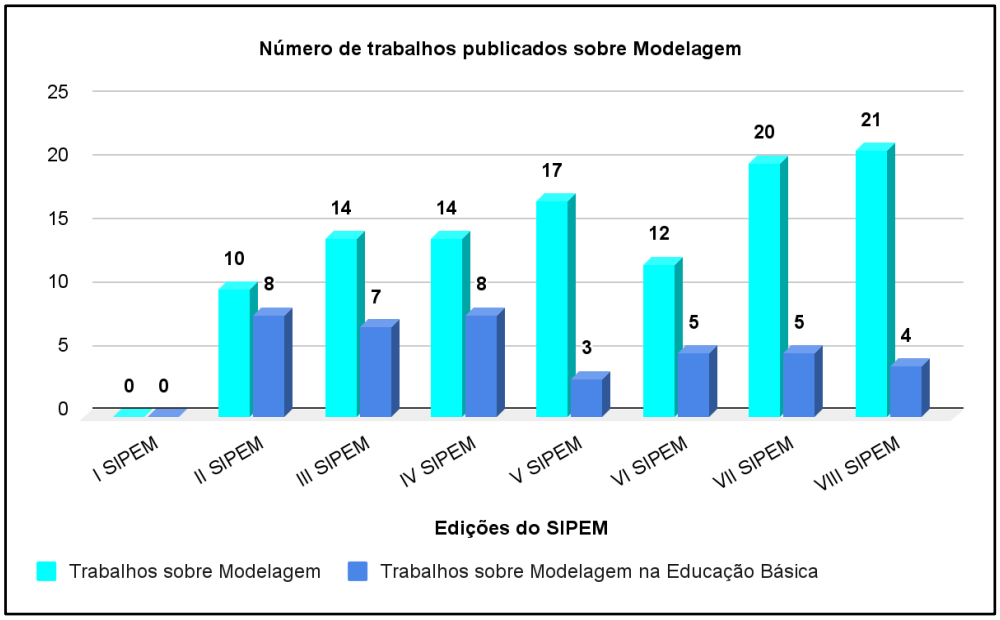

Figure 2.

Published papers on mathematical modeling in each SIPEM edition(Own elaboration)

As highlighted in Figure 2, only in two editions, the 2nd SIPEM and 4th SIPEM, are the number of research studies addressing mathematical modeling in basic education mostly related to the total number. It is also noteworthy that, even though the number of articles on modeling has increased, comparing the first and the last editions, we see that the quantity of actions aimed at basic education has not grown.

Given these preliminary considerations, we carried out a more specific search to analyze the themes in the studies that dealt with the theme chosen for the present research. Thus, following the chronological order, we analyzed the proceedings of the first edition of SIPEM, held in November 2000. The topic discussed was "Research on mathematics education in Brazil." No works addressing mathematical modeling were found in the analysis of that edition's data, as already revealed in Figures 1 and 2. We know that the justification for this is that Working Group 10 (in Portuguese GT 10), related to mathematical modeling, was created only in 2001, after the 1st SIPEM. However, it is worth highlighting that the summary booklet of the 1st SIPEM indicates the existence of WG 10. However, as a group receiving papers for exhibitions and presentations, it was activated only from the 2nd SIPEM onwards.

Thus, we moved on to the following edition of October 2003, when the "Contribution of research to the mathematics teachers' education" was debated. In this seminar, researchers began discussing ongoing research, the obstacles encountered, and the necessary improvements. They also defined priorities and new fields of investigation in addition to those

already existing at the time. Thus, two more WGs were added to the nine existing in the 1st SIPEM. With a careful investigation of the event's proceedings, we could select the following works (Table 2):

Table 2.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 2nd SIPEM

WG	Title	Author(s)
5	A Modelagem matemática na perspectiva da etnomatemática: possibilidades e obstáculos no processo de escolarização [Mathematical modeling from the perspective of ethnomathematics: possibilities and obstacles in the schooling process]	Alexandrina Monteiro
10	Buscando evidências de aprendizagem significativa nas produções dos alunos, em ambiente de modelagem matemática [Seeking evidence of significant learning in student productions, in a mathematical modeling environment]	Adriana Helena Borssoi and Lourdes Maria Werle de Almeida
	A integração entre modelagem matemática, interdisciplinaridade e tecnologias da informação e comunicação na sala de aula [The integration of mathematical modeling, interdisciplinarity, and information and communication technologies in the classroom]	Ana Paula dos Santos Malheiros
	O tratamento de questões ambientais através da modelagem matemática: uma proposta de trabalho com alunos do ensino fundamental [Addressing environmental issues through mathematical modeling: a proposal for work with elementary school students]	Denise Helena Lombardo Ferreira
	Modelagem matemática e perspectiva sócio-crítica [Mathematical modeling and socio-critical perspective]	Jonei Cerqueira Barbosa
	Modelagem matemática em sala de aula: imaginação ou realidade? [Mathematical modeling in the classroom: imagination or reality?]	Jussara de Loiola Araújo
	Princípios de Metamodelagem Matemática [Principles of mathematical metamodeling]	Nelson Hein and Maria Salett Biembengut
	Uma proposta transdisciplinar, a educação de jovens e adultos e a modelagem matemática [A transdisciplinary proposal, youth and adult education, and mathematical modeling]	Lênio Fernandes Rodrigues and Adilson Oliveira do Espírito Santo

Regarding Table 2, it is worth highlighting that, in addition to the seven works from WG 10 (a group dedicated mainly to mathematical modeling), we detected one paper from WG

5 (dedicated to the areas of the history of mathematics and ethnomathematics). In this edition, unlike the first, eight academic productions were found under the bias of the theme under study. After that, we searched for works published in the annals of the 3rd SIPEM, held in October 2006, which brought together around 300 researchers. The results of this search are shown in Table 3:

Table 3.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 2nd SIPEM

WG	Title	Author(s)
10	Algumas reflexões sobre a pesquisa em modelagem matemática [Some reflections on research in mathematical modeling]	Lourdes Maria Werle de Almeida
	Os modelos matemáticos e a sua importância para o ensino de física no ensino médio [Mathematical models and their importance for teaching physics in high school]	Cláudia de Oliveira Lozada, Wagner Morrone, Mauro Sérgio Teixeira de Araújo and Luiz Henrique Amaral
	O tratamento de questões ambientais através da modelagem matemática: um trabalho com alunos do ensino fundamental e médio [Addressing environmental issues through mathematical modeling: a work with elementary and high school students]	Denise Helena Lombardo Ferreira and Maria Lúcia Lorenzetti Wodewotzki
	O ambiente de modelagem matemática e a aprendizagem dos alunos: relatos de experiência [The mathematical modeling environment and student learning: experience reports]	Arthur Gonçalves Machado Júnior, Adilson Oliveira do Espírito Santo and Francisco Hermes Santos da Silva
	A dinâmica das discussões dos alunos no ambiente de modelagem matemática [The dynamics of student discussions in the mathematical modeling environment]	Jonei Cerqueira Barbosa
	Experiências de ensino por meio da modelagem matemática no ensino fundamental [Teaching experiences through mathematical modeling in elementary education]	Lozicler Maria Moro dos Santos and Vanilde Bisognin
	Modelagem matemática no ensino médio: uma alternativa para a melhoria do processo de ensino e aprendizagem [Mathematical modeling in high school: an alternative for improving the teaching and learning process]	Karla Jaqueline Souza Tatsch and Vanilde Bisognin

As highlighted in this table, seven articles were selected on the chosen theme, more than in the previous edition. Next, we have the results obtained at the 4th SIPEM, held in October 2009, which included several changes in the presentation model and the research debate. In this

case, it was possible to use a search technique (or shortcut) by pressing the CTRL + F keys on the keyboard. After that, we had to type the keywords we initially chose into the search box. After this initial search and reading of the abstracts, the following studies were listed (Table 4):

Table 4.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 4th SIPEM

WG	Title	Author(s)
2 and 3	Contribuições para o numeramento em turmas do EJA [Contributions to numeracy in YAE classes]	Anneliese de Oliveira Lozada, Cláudia de Oliveira Lozada and Edilene Farias Rozal
10	Reflections on the notion of interest in mathematical modeling projects	Maria Helena Garcia Barbosa Herminio and Marcelo de Carvalho Borba
	Bases epistemológicas e implicações para práticas de modelagem em sala de aula [Epistemological bases and implications for modeling practices in the classroom]	Tiago Emanuel Klüber and Dionísio Burak
	A modelagem matemática no processo de ensino-aprendizagem e o paradigma epistemológico da complexidade [Mathematical modeling in the teaching-learning process and the epistemological paradigm of complexity]	Lênio Fernandes Levy and Adilson Ferreira do Espírito Santo
	Reformulação de estratégias em modelagem matemática: quando os alunos desafiam a condução do professor [Reformulation of strategies in mathematical modeling: when students challenge the teacher's guidance]	Marcelo Leon Caffé de Oliveira and Jonei Cerqueira Barbosa
	Modelagem matemática: contexto para a construção do conhecimento matemático [Mathematical modeling: context for the construction of mathematical knowledge]	Elaine Cristina Ferruzzi and Lourdes Maria Werle de Almeida
	Modelagem matemática na sala de aula: uma compreensão acerca da resistência dos alunos [Mathematical modeling in the classroom: understanding student resistance]	Andréia Maria Pereira de Oliveira, Jonei Cerqueira Barbosa and Thaine Souza Santana
12	A educação estatística no ensino médio por meio da Mmodelagem matemática [Statistical education in high school through mathematical modeling]	Luzinete de Oliveira Mendonça and Celi Espasandin Lopes

The results showed one paper from WG 2 and 3 (groups that debate mathematics education in middle and high school), six works from WG 10, and one work from WG 12 (group dedicated to research on the teaching of probability and statistics), totaling eight works.

Below are the productions obtained in the 5th SIPEM (Table 5). In this edition, in October 2012, the event addressed the theme of "Epistemological, theoretical, and practical questions of research in mathematics education" with the participation of 313 registered researchers.

Table 5.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 5th SIPEM

WG	Title	Author(s)
10	A tensão da elaboração da situação-problema no planejamento do ambiente de modelagem matemática [The tension of developing the problem situation in the planning of the mathematical modeling environment]	Lilian Aragão da Silva and Andreia Maria Pereira de Oliveira
	Os "discursos de distanciamento" dos professores no ambiente de modelagem matemática [Teachers' "distancing discourses" in the mathematical modeling environment]	Maiana Santana da Silva and Thaine Souza Santana
	Textos sobre matemática em uma prática pedagógica no ambiente de modelagem nos anos iniciais [Texts on mathematics in pedagogical practice in a modeling environment in the initial years]	Ana Virginia de Almeida Luna, Elizabeth Gomes Souza and Larissa Borges de Souza Lima

Inspecting Table 5, it is notable that, in this edition, there were significantly fewer results, with a total of three works from WG 10. In November 2015, the 6th SIPEM took place, with the participation of around 319 researchers, divided into 13 WGs. Table 6 below shows the results identified in the proceedings of that edition:

Table 6.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 6th SIPEM

WG	Title	Author(s)
10	A 'escolarização' do espaço vivido nas atividades de modelagem com geometria: uma compreensão sob a perspectiva fenomenológica [The 'schooling' of lived space in modeling with geometry activities: an understanding from a phenomenological perspective]	Dirceu dos Santos Brito, Camila Fogaça de Oliveira and Cíntia da Silva Milani
	A primeira experiência em modelagem matemática de alunos do sexto ano do ensino fundamental [The first experience in	Neil da Rocha Canedo Junior and Marco Aurélio Kistemann Junior

WG	Title	Author(s)
	mathematical modeling of sixth grade students of elementary school]	
	Modelagem matemática e aprendizagem de geometria: possíveis aproximações por meio de vídeos [Mathematical modeling and geometry learning: possible approaches through videos]	Maisa Lucia Cacita Milani, Lilian Akemi Kato and Valdinei Cezar Cardoso
	Modelagem matemática: relação entre formulação de perguntas e elaboração de tarefas [Mathematical modeling: relationship between question formulation and task development]	Marilaine de Fraga Sant'ana and Alvino Alves Sant'ana
	Modos de praticar matemática em modelagem matemática [Ways to practice mathematics in mathematical modeling]	Elizabeth Gomes Souza and Ana Virginia de Almeida Luna

This table shows that only five works were selected, all from WG 10. At the 7th SIPEM, which took place in November 2018, the theme discussed was "Social justice and mathematics education," with 365 registered researchers organized into 15 WGs. Table 7 features the selected works from this edition.

Table 7.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 7th SIPEM

WG	Title	Author(s)
5	Um currículo trivium para a matemática fundamentado nas perspectivas da etnomatemática e da modelagem [A trivium curriculum for mathematics based on the perspectives of ethnomathematics and modeling]	Milton Rosa and Daniel Clark Orey
10	As práticas com modelagem matemática na educação básica do Paraná: um olhar [Practices with mathematical modeling in basic education in Paraná: noticing it]	Dionisio Burak and Daniele Regina Penteado
	A inteiração e a matematização em atividades de modelagem matemática [Integration and mathematization in mathematical Mmodeling activities]	Thiago Fernando Mendes and Camila Fogaça de Oliveira
	Reflexiones sobre metodología crítica en ambientes de modelación matemática: dos investigaciones en el contexto colombiano [Reflections on critical methodology in mathematical modeling environments: two investigations in the Colombian context]	Gabriel Mancera, Francisco Camelo and Jussara de Loiola Araújo

	Teaching practices with mathematical modeling: influences of moments experienced in initial education	Barbara Candido Braz, Wellington Piveta Oliveira and Lilian Akemi Kato

As highlighted in Table 7, among the papers of the 7th SIPEM, we selected one from WG 5 and four from GT 10 for analysis. Its last edition, the 8th SIPEM, was held in November 2021, presenting as its central theme "Mathematics education, pandemic, post-pandemic, and the present: implications for research and teaching and learning practices." Table 8 below shows the works analyzed at the 8th SIPEM:

Table 8.

Description of published works on mathematical modeling in the teaching-learning process in basic education in the 8th SIPEM

WG	Title	Author(s)
5	Concepções de modelagem matemática nas pesquisas em etnomodelagem [Conceptions of mathematical modeling in ethnomodeling research]	Zulma Elizabete de Freitas Madruga
	Inquietações quanto aos processos de etnomodelagem: a questão da linguagem e da insurreição dos saberes locais e suas relações com a matemática acadêmica disciplinar [Concerns about ethnomodeling processes: the question of language and the insurrection of local knowledge and its relations with academic disciplinary mathematic	Rafael Bida Guabiraba Martins and Ademir Donizeti Caldeira
10	Ludicidade em atividades de modelagem matemática na educação infantil e no ensino fundamental [Playfulness in mathematical modeling activities in early childhood education and elementary school]	Antonella Fernandes and Emerson Tortola
	Recursos semióticos na produção de signos em atividades de modelagem matemática [Semiotic resources in the production of signs in mathematical modeling activities]	Paulo Henrique Hideki Araki and Karina Alessandra Pessoa da Silva

Table 8 shows seven published works on modeling from the perspective of teaching-learning in mathematics in basic education, namely, two from WG 5 and two from WG 10.

It is important to highlight that, given the theme chosen for this study, some published academic productions were not selected for our analysis because of their contexts. One example is research focused on teacher education. Furthermore, many articles did not clarify whether the research contemplated the mathematics teaching-learning process for basic education

students. Another noticeable point is that given the summarized way some papers were presented, some information that should meet editorial issues, such as the number of pages, could not be analyzed.

What do the selected works indicate?

After identifying, selecting, and previously analyzing the academic productions of all editions of SIPEM, a more careful reading sought to identify: What can be observed in research that has explored mathematical modeling in basic education?

Classifying the selected works according to the WG

As seen previously, we selected works from different WGs and identified that the most outstanding were WG 5 and WG 10. In the works by WG 5 (researchers develop investigations in the areas of the history of mathematics and ethnomathematics), it is clear that the authors established a relationship between the study of ethnomathematics and modeling (which they also call ethnomodeling) in different contexts in the educational environment. In the 2nd SIPEM, Monteiro (2003) brings the perspective that ethnomathematics is a philosophical proposal, seeking to reverse the process of recreating everyday tactics and knowledge (often, this knowledge is silenced), requiring the teacher to commit to effective learning of excluded and disadvantaged groups.

In this sense, the author cites mathematical modeling as a vital tool in realizing students' knowledge. Both trends in mathematics education complement each other. Rosa and Orey (2018) mention the curriculum issue involving trivial mathematical content for teaching mathematics in basic education, basing their ideas on different perspectives in the face of ethnomodeling, in which they comment on the need for these propositions in the role of encouraging teachers in identifying teaching and learning practices in mathematics and their pedagogical actions.

Another mention of this relationship occurs when Madruga (2021) understands ethnomodeling based on the assumptions of ethnomathematics as a methodological proposal that comes together with mathematical modeling to enhance learning at different levels of education. Madruga realized that the tangency between the conceptions of modeling that underpin the research occurs in two directions: the idea of modeling from a socio-critical perspective, as a method, or as a teaching strategy. The author concludes by saying that, for students to understand mathematical content, ethnomodeling ends up providing learning based

on respect and cultural appreciation.

On the other hand, SIPEM created WG 10, a working group entirely focused on investigation and research on mathematical modeling. Lozada, Morrone, Araújo, and Amaral (2006) address how mathematical models are necessary for solving physics problems. However, in the vast majority, they are not well developed by students due to their mathematical difficulties. Teachers must be attentive to these difficulties as they perceive them and thus seek teaching strategies that provide the basic skills necessary to develop mathematical models applied to physics. The relationship between interdisciplinarity and mathematical modeling is also debated by Ferreira (2003) and Ferreira and Wodewotzki (2006), who bring to light how environmental issues can be addressed in elementary and high school.

Such research seeks to understand how student participation occurs, and which socio-pedagogical elements are present in these issues. The proposed pedagogical action involving mathematical models addressed topics such as water, waste, electricity, and deforestation, with the step in which models would be created, including the prediction of population growth, water consumption, waste production, and electricity in the city. The activity, in addition to providing a glimpse into fields rich in applications, also allowed students to integrate their experience with mathematics, enabling them to collect data and formulate and solve problems while becoming more environmentally aware.

Malheiros (2003), in turn, highlights the use of information and communication technologies (ICTs) in the classroom and how they can benefit the teaching-learning process of students since they carry out experiments through investigative work to solve problems in which, in this environment, modeling is used as a pedagogical strategy in teaching mathematics.

Hein and Biembengut (2006) deal with the principles of metamodeling, in which they propose a process of obtaining a mathematical model from scientific research in which students go beyond school limits. From there, students are expected to develop and understand the types of models that exist and which is the most appropriate for each situation, and only then use them correctly in problem-solving.

Fernandes and Tortola (2021) discuss how we can explore playfulness through activities involving modeling with early childhood education and elementary school students. However, despite being characteristic in pedagogical practices, predominantly in the first school years, it is still little discussed and needs clarification, so its adjectivization is made without a sustainable theoretical foundation.

According to Braz, Oliveira, and Kato (2018), it is in experiences in formative contexts that involve shared actions between prospective teachers, in-service teachers, and teacher

educators that the possibility of establishing relationships between the theory and practice of modeling and the encouragement of the development of modeling practices by prospective teachers becomes evident. Therefore, in this sense, the study shows that experience at different moments within the scope of initial education can help develop mathematical modeling practices, which educators can implement later.

We also found productions on modeling as a teaching resource in the mathematics teaching-learning process for YAE classes. Lozada, Lozada, and Rozal (2009) discuss how mathematical models can contribute in this context. Furthermore, there were productions involving the teaching of mathematical content in statistics, discussed by Mendonça and Lopes (2009), for high school classes, in which modeling acts as a pedagogical tool. These works were taken from the discussions and research by WGs 2 and 3 (groups that debate mathematics education in middle and high school) and WG 12 (a group dedicated to research on the teaching of probability and statistics), respectively.

Thematic contexts addressed by the works selected in the research

Among the 40 works selected for this research, it is still possible to highlight and organize the data found, considering the themes discussed in these productions in the editions of the event. Among the approaches observed in the analysis, discussions were developed relating mathematical modeling to early childhood education, elementary education, and high school; in YAE (Youth and Adult Education) classes; in ethnomathematics; in geometry; in statistics; in physics; associated with ICTs (information and communication technologies); in didactic and curriculum issues; in experience reports; and others.

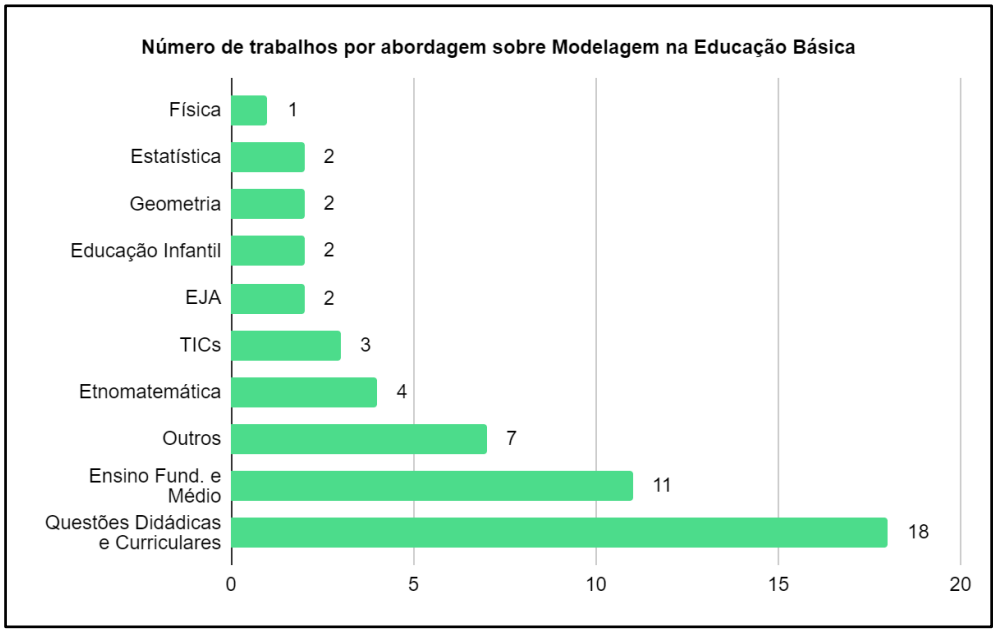

Figure 3.

Works on mathematical modeling in the teaching-learning process in basic education at SIPEM by approach (Own elaboration)

It is important to highlight that some of the selected works may simultaneously assume more than one approach. An example of this is the work by Fernandes and Tortola (2021), who address early childhood education and elementary education as the scope of the study.

Among the works with themes related to different contents, there is that of Borssoi and Almeida (2003), which relates mathematical modeling and meaningful learning, as they understand that student learning is linked to the actions that characterize "mathematical doing" in a way that provides the student with the opportunity to experiment and model, as well as to analyze situations and develop their critical spirit based on the results obtained. Barbosa (2003) discusses, from modeling theoretical perspectives, the application of the socio-critical classification presented by the German researcher Kaiser-Messmer. Barbosa conceives the practice of modeling as a means of socializing students in the reflection of mathematical concepts.

Araújo's work (2003) briefly addresses the subject, using the same socio-critical view, contemplating philosophical ideals, and relates mathematics to reality from this perspective since this reality is addressed in problem situations in various mathematical contents. Besides Lozada, Lozada, and Rozal's (2009) work, Rodrigues and Espírito Santo (2003) deal with a transdisciplinary proposal in the teaching-learning environment in YAE (youth and adult education) classes, so that modeling is taken from the ideas of Edgar Morin, who defends the

construction of connections between some elements of human culture and the distinction and direction between the parts towards the whole.

Following this bias, one can also contemplate the knowledge acquired in real practices, knowledge, and experiences (in the ethnomodeling environment), which end up not being legitimized but have great value. Martins and Caldeira (2021) show this in their research, which had as its theoretical foundation the philosophical concepts by Michel Foucault and Ludwig Wittgenstein for mathematics education.

Almeida (2006), in turn, aggregates the production of reflections on the development of knowledge through mathematical models within the scope of mathematics education and only then presents a brief report of some research developed. Many works analyzed in this research bring reports of experiences where modeling was or can be inserted. This is the case of the academic productions of Junior, Espírito Santo, and Silva (2006) and Barbosa (2006), which quickly bring reflections on student learning to help teachers improve their teaching practices.

In this same context, Santos and Bisognin (2006) describe the results of experiments carried out in class based on research carried out in a middle school 8th grade using modeling as a methodological teaching strategy and addressing environmental issues through the theme of air, soil, and water pollution, working on basic statistics concepts. Using a qualitative approach, Barbosa (2006) filmed, transcribed, and analyzed a class and later used notions of mathematical, technical, and reflective discussions to raise a hypothesis that such discussions occurred due to impasses.

On the other hand, Tatsch and Bisognin (2006) discuss a classroom methodology using modeling as a teaching tool. The target audience is a 1st-grade high school class at a public school in Rio Grande do Sul. Based on the theme "Food: questions about obesity and malnutrition," the researchers developed activities to put students' knowledge into practice, aligning with their realities. Oliveira and Barbosa (2009) used filming for a methodological approach to an activity applied to an 8th-grade middle school class in a public school in Conceição do Jacuípe, in Bahia.

Analyzing the recordings, the authors suggest that a modeling activity that refers to students' daily lives and how they interpret the teachers' statements can encourage them to reformulate the proposed strategy. Both Oliveira, Barbosa, and Santana (2009) and Silva and Oliveira (2012) felt that students resisted the modeling environment due to, for example, the strangeness of the proposal and the lack of familiarity with it. To deal with this tension, Silva and Oliveira comment that the teacher adopted a strategy to alleviate it and condition it to pedagogical practice.

This resistance is also cited in Silva and Santana (2012), who, based on an experience report by a teacher from Feira de Santana in Bahia, comment on teachers' discourses of distancing themselves from the characteristics of this environment, including modeling. According to research by Luna, Souza, and Lima (2012) on the utilisation of modeling in the initial years of elementary education, there is the application of an analysis of how mathematical discourse texts are produced. The proposed experiment included a teacher and her twenty-seven students, aged between nine and eleven, from the 5th grade of a private educational institution. It is common knowledge that ICTs can bring countless benefits when implemented in the learning context. In this sense, Milani, Kato, and Cardoso (2015) proposed investigating some of the potentialities of using videos that accompany high school textbooks in geometry studies. The results found in the investigation indicated that the quality of these videos generates objects within these environments for obtaining mathematical knowledge. However, Sant'ana and Sant'ana (2015) discussed the relationship between the previous questions prepared by a teacher while creating a mathematical modeling activity and the role that he or she effectively plays in the classroom.

In this context, regarding the ways of practicing the contents using mathematical models, Souza and Luna (2015) and Mendes and Oliveira (2018) start from theoretical assumptions of mathematical modeling to present some activities developed by pre-service teachers, directed to the interaction and mathematization stages of modeling and how they can influence the resolution of mathematical problems. Like them, Burak and Penteado (2018) and Mancera, Camelo, and Araújo (2018) portray, through experience reports, how modeling practices developed in basic education in schools in Paraná and Colombia, respectively, are not yet effectively present.

However, Mancera, Camelo, and Araújo (2018) started from a socio-critical view of real and imagined situations, organized dynamically, allowing for an investigative pedagogical practice. Junior and Junior (2015) aimed to investigate students' participation and decision-making in modeling environments. The results of this research showed that the presence of media in constructing mathematical models surpasses that of artifacts, as they not only mediate individuals' actions but participate in these actions and influence the activity as a whole. Another result obtained in the study was that the presence of mathematical modeling as a teaching approach proposed by several teachers within the scope of basic education favors and demands the development of student autonomy.

Still from this perspective, which discusses didactic and curriculum issues, Klüber and Burak (2009) indicated the need for studies on the epistemological bases based on the practice

of modeling in the classroom. Adopting a phenomenological investigation, the authors implied the recognition of some essential aspects of this trend in mathematics education, particularly in basic education. In this same framework, Levy and Espírito Santo (2009) take a historical basis that involves mathematics and philosophy, especially that of knowledge, toward students' awareness, supported by the epistemological paradigm of complexity. Brito, Oliveira, and Milani (2015) also adopted a phenomenological stance related to philosophy in light of the methodological aspects used in the research development.

Other ideas are brought to light in some works, such as Hermínio and Borba (2009), who outlined a theoretical framework through the notion of interest based on the works of Dewey and Schutz, and from there, based reflections on what is relevant for students, as well as indicated points in which such foundations could be improved in future research. According to research by Ferruzzi and Almeida (2009), they characterized mathematical modeling through a simulated context and assumed as their objective the search for identifying, in episodes developed in this same context, some cognitive processes considered important for the construction of mathematical knowledge.

In another vein, Araki and Silva (2021) addressed and questioned how different middle school students mobilize semiotic resources to develop mathematical modeling activities. Analyzing the results achieved after the experimentation proposed in the study, they found that this mobilization of resources occurs in response to three specific needs: problematization, the experimental approach, and mathematization, so that all were associated with the problem, the observed phenomenon, and the mathematical objects.

Some quantitative aspects of the results obtained by the research

In addition to the 40 works on the topic addressed in this study, it is also possible to highlight some quantitative aspects in light of the survey results. Based on the analysis of the proceedings of the eight editions of SIPEM relating the number of published works and those that dealt with modeling in basic education, the following figure was created:

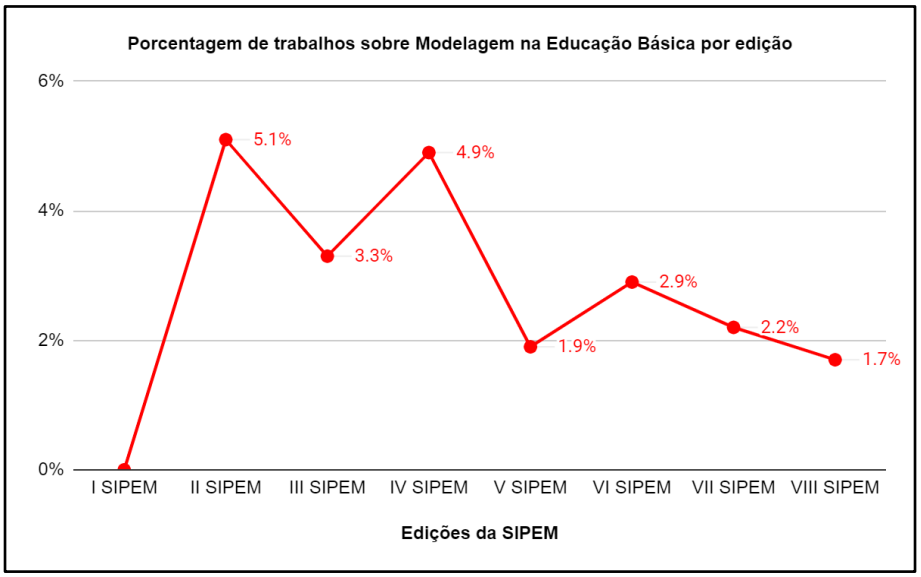

Figure 4.

Percentage of papers on modeling in the teaching-learning process in basic education in the SIPEM editions (Own elaboration)

Figure 4 shows the notable variation in the quantitative aspect of the works published on modeling in basic education in each edition. We observed, as highlighted above, that the 1st SIPEM had no research on this topic among 112 published papers. In the 2nd SIPEM, the number of published works had a consequent increase, also due to the creation of new WGs (from 9 groups to 12). Thus, research on modeling was further explored. Of 156 published works, 5.1% addressed mathematical modeling directly inserted in basic education teaching-learning. In the third edition of SIPEM, nine of 211 academic productions published dealt with modeling, representing a percentage of 3.3%. This percentage increased in the 4th SIPEM since, of 162 works, 4.9% were about modeling in basic education.

The fifth edition of the event had the lowest percentage of published works on mathematical modeling, with only 1.9%. Later, at the 6th SIPEM, this number grew again a little, rising to 2.9%. In the seventh edition, we returned to the mark of 2.2% of published works on modeling. Finally, in the 8th SIPEM, of 226 academic productions published, seven addressed modeling, which gave us a percentage of 1.7%. Of 964 productions, only 40 were about approaches to modeling in basic education mathematics teaching-learning process, on average, 4.1%. Therefore, the second edition explored this theme the most, surpassing the general average, reaching 5.1% of the published works.

Final considerations

In this research, we analyzed 40 scientific works produced between 2000 and 2021, published in the proceedings of the eight editions of SIPEM, in a total of 964 works. As seen during the study, among the analyzed works in the first edition of the event, no one mentioned modeling in the teaching-learning process of mathematics for basic education students (early childhood education, elementary and high school), unlike the 2nd SIPEM, which contained eight academic productions, which correspond to 5.1%. In the 3rd SIPEM, despite the increase in the number of works published in a general context, 3.3% talk about mathematical models, of which nine were published that year (2006). The fourth edition of the event counted 4.9% of published articles on modeling.

In the following editions, this percentage only decreased, and the last edition of the event, the 8th SIPEM, presented the lowest percentage of productions on mathematical modeling, after the 1st SIPEM. Although this data is considerably small, it expresses the recognition of this area, mainly regarding the teaching-learning process, whether it is being used as a pedagogical resource in classes or as a study instrument for other research on different topics. Furthermore, other trends in mathematics education are also expanding and are eventually directly associated with modelings, such as ethnomathematics and problem solving.

In this sense, it is also worth highlighting some considerations about the central question of this study, in which we sought to verify the following question: What can be observed in research that explores mathematical modeling in basic education?

The analyzed research reveals that mathematical modeling has been used at different levels of education to address different mathematical content, be it geometry, algebra, or numbers, for example. Mathematical modeling also favors the development of interdisciplinary work between mathematics and other disciplines, as seen with physics, according to the study by Lozada, Morrone, Araújo, and Amaral (2006).

It is also possible to observe that mathematical modeling is configured as a learning environment, as students are invited/encouraged to get involved in a given activity, to think mathematically, and, starting from and through this, to solve a problem that brings a theme from reality. Among these themes, electricity consumption, water consumption, air pollution, and monthly supermarket shopping expenses were highlighted.

In these terms, we realize that mathematical modeling places students as actors in the teaching and learning process, especially when it makes them inquire and investigate themes through mathematics. Given these numerous themes that can be explored, we understand that

mathematical modeling favors interdisciplinary study, as already mentioned, and allows the teacher to work with projects in the school environment.

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