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ARTIGO ORIGINAL

Model Conceptions in Science Education Research: features and trends

Concepções de Modelo na Pesquisa em Educação em Ciências: características e tendências

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Abstract: Despite the ubiquity of models in science education, there are several different conceptions about their nature in the scientific community. We sought to investigate understandings about them conveyed in the recent research in science education. To this end, we have reviewed papers published on models and modelling between 2010 and 2019. Our analysis revealed that these different notions on the concept of model could be represented in three main trends: Concrete, Construct and Mathematical. In addition, we found that these studies: are predominantly empirical in nature; involve frameworks arising mainly from science education research itself, but with a considerable influence from Philosophy of Science and cognitive sciences; encompass Physics, Biology and Chemistry domains in relatively similar frequencies, but decreasing in this order. Another outcome of this study was the emergence of different scenarios regarding the journals consulted, revealing the existence of different thought styles in science education research community.
Keywords: Modelling; Science education; Philosophy of science; Literature review.

Resumo: Apesar da onipresença de modelos no ensino de ciências, existem várias concepções diferentes sobre sua natureza na comunidade científica. Procuramos investigar os entendimentos sobre modelos veiculados nas pesquisas recentes em educação em ciências. Para tanto, revisamos artigos publicados sobre modelos e modelagem entre 2010 e 2019. Nossa análise revelou que essas diferentes noções sobre o conceito de modelo podem ser representadas em três tendências principais: Concreto, Construto e Matemático. Além disso, descobrimos que esses estudos são predominantemente de natureza empírica, envolvem referenciais decorrentes principalmente da própria pesquisa em educação científica, mas com considerável influência da Filosofia da Ciência e das ciências cognitivas, e abrangem os domínios da Física, Biologia e Química em frequências relativamente semelhantes, mas decrescendo nesta ordem. Outro resultado deste estudo foi o surgimento de diferentes cenários em relação aos periódicos consultados, revelando a existência de diferentes estilos de pensamento na comunidade de pesquisa em educação em ciências.
Palavras-chave: Modelagem; Educação científica; Filosofia da ciência; Revisão de literatura.

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Introduction

As the relevance of models became more widely recognized in philosophy of science and in cognitive psychology, science education researchers also became interested in their role in science teaching and learning. Although discussions about models in this field were incorporated as an area of investigation mainly in the 1980s, the *meanings* attached by students and experts to the word *model* (in science education contexts) were first investigated at the beginning of the 1990s. Having a rich body of literature defending the need for teaching students how to practice modelling (CLEMENT, 1989; COLL; LAJIUM, 2011; HARRISON; TREAGUST, 1998; HESTENES, 2010) and proposing approaches on how to implement these kind of practice in science classrooms (for example, GILBERT; JUSTI, 2016; LEHRER; SCHAUBLE, 2000; SCHWARZ *et al*., 2009; SVOBODA; PASSMORE, 2013, among many others), it is natural to ask about the nature of the underlying construct: the model. What is this element being constructed, evaluated, revised? How is the concept of model being understood in science education literature? As will be discussed in the following section, this is quite a polysemous word (CHAMIZO, 2013; OH; OH, 2011).

In addition to its polysemy, when observing the uses of the word *model* in research papers in science education we have been noticing that the actual conception of model underlying these studies is sometimes not clearly stated, remaining implicit (CHENG; OON, 2016; SLATER; MORRIS; McKINNON, 2018; SMOTHERS; GOLDSTON, 2010). As a result, quite different approaches are fused together under the same label of *model* or *modelling*. In our view, understanding this multiplicity of meanings and making one's own option explicit is relevant because different conceptions about models might entail different skills and abilities to be developed by students, different purposes and approaches when designing modelling activities, different metamodelling knowledge, as well as different understandings about nature of science itself. Based on this perspective, the present study seeks to investigate which conceptions about models and modelling have been implemented recently in the area of science education, as well as to gather information about general characteristics of the research on this subject. So, the following research questions guided this investigation: (1) how are studies on models and modelling characterized in terms of the type of approach (theoretical or empirical), the scientific disciplines involved and the theoretical influence of other fields of investigation?; and, (2) what conceptions about the notion of model are conveyed in the recent research published on the subject of models and modelling in the area of science education?

Overview

What is a model? Despite their ubiquity, there are several different conceptions about the nature of models in the scientific community. The polysemous character of the word is such that some scholars even try to avoid assuming any definition at all (for example, GOGOLIN; KRÜGER, 2018; TALA 2011). This diversity of conceptions about models occurs not only in science education research, but in philosophy of science as well. Some philosophers conceptualize models as essentially analogical

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elements (BLACK, 1962; HESSE, 1966), while others depict them as providing other kinds of representation, such as being mediators between theories and the world (BUNGE, 1973; MORGAN; MORRISON, 1999) or as set-theoretical structures, a notion closely tied to mathematical models (SUPPE, 1961; VAN FRAASSEN, 1980). Still others provide a non-representational account of models, defining them as epistemic artifacts (KNUUTTILA, 2005).

Considering the plurality of ideas in philosophy of science itself, it is actually not surprising to find different understandings about the nature of models in science education research literature. For instance, views emphasizing models as analogies are very popular in the field (CHAMIZO, 2013; CLEMENT, 1989; DUIT; GLYNN, 1996; DUPIN; JOSHUA, 1989; GILBERT; BOULTER; RUTHERFORD, 1998). In contrast, a considerable number of studies approach model construction as the elaboration of a mathematical representation of a certain phenomenon (GRANDY, 2003; HESTENES, 1987; SCHUCHARDT; SCHUNN, 2016; UHDEN *et al*., 2012). But there are also works conceiving models as some other form of representation, not necessarily analogical or mathematical (JONG; CHIU; CHUNG, 2015; MACHADO; BRAGA, 2016; MENDONÇA; JUSTI, 2014).

Given the growing relevance assigned to models in science education, some researchers have investigated students' and teachers' understandings about their nature (for example, GOBERT *et al*., 2011; GROSSLIGHT *et al*., 1991; JUSTI; GILBERT, 2003; TREAGUST; CHITTLEBOROUGH; MAMIALA, 2004). Findings from these studies mostly indicate that both students and teachers tend to hold a naïve form of realism regarding the nature of models, meaning they tend to conflate the model with the real object supposedly represented by the model. This notion of models as copies, or *replicas*, seems to persist even among students with fairly good understandings about other aspects of models (CHENG; LIN, 2015). As for teachers, this idea of models as replicas was the only aspect in which their understandings were not better than students', according to a recent comparative study by Cheng, Wu and Lin (2019). Furthermore, some studies investigated the relationship between students' views on models (or *metamodelling knowledge*) and their science learning performance (GOBERT *et al*., 2011; KRELL; ZU BELZEN; KRÜGER, 2014; PARK, 2013; SCHARZ; WHITE, 2005). Overall results indicate that students with more elaborated understandings about models tend to also have better outcomes in learning science contents. Among recent literature reviews on the subject of models and modelling in science education, Namdar and Shen (2015) developed a comprehensive study summarizing the research from 1980 to 2013. However, their work focused specifically in the dimension of assessment related to this subject, or modelling-oriented assessment (MOA). Oh and Oh (2011), in their literature review about models and their uses in science education, pointed out that, despite the absence of a unique definition, the term *representation* is commonly used to explain what a model is. However, sharing this terminology does not necessarily indicate agreement, either; as we have mentioned, different scholars have different ideas in mind when they refer to models as representations.

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Methods

Sample and data collection

Given the ubiquity of models and modelling discussions in the literature, we first had to delineate the scope of this research. Four journals were selected to be included in our sample for having rich productions in the specific subject under investigation, broad international circulation, high impact factors, being peer-reviewed and for encompassing science education as a whole, without focusing on a single specific discipline: Science Education (SE), International Journal of Science Education (IJSE), Journal of Research in Science Teaching (JRST) and Science & Education (Sc&E). To select papers for inclusion, we first carried out a search for the terms *model*, *models*, *modelling* (or *modeling*) across the fields title, abstract and descriptor in each journal, using electronic database Educational Resources Information Center (ERIC) and including issues published in the last ten years, ranging from 2010 to 2019. This initial search resulted in 705 papers.

Since we were interested in models as epistemic objects to be conceptualized by students in teaching processes, our next step was to create a corpus including only papers dealing with this meaning of the word *model*. Therefore, many papers found by the search engine had to be discarded, for failing to meet these criteria. Among the most frequent cases of excluded papers were those dealing with teaching models, pedagogical models (as synonym for teaching models), sociological models, instructional models, models of research, model-organisms, role models, models of assessment, curriculum models, psychometric models (such as the Rasch model), professional development models, statistical models for data analysis (such as hierarchical linear model or structural equation modelling), models of didactic processes (such as the conceptual change model) and models in the sense of exemplars. This selection process was carried out manually, since no other search terms would be able to separate out these occurrences from those we were looking for. In most cases, abstracts provided enough information to decide whether the paper should be discarded. After this refinement, the resulting corpus consisted of 200 occurrences. Throughout the coding process, a few more papers had to be discarded for other reasons. Five of them could not be categorized due to lack of sufficient information in one or more of the analytical axes. Four were discarded on account of ambiguity, since they could be assigned to more than one model category with the same degree of emphasis. Lastly, two other papers were excluded because they consisted in categorizations of models themselves. This left 189 papers in our effectively analyzed corpus.

Data analysis

Following our research questions, we divided our analysis into two levels. Concerning general characteristics of modelling studies, we inventoried data about (1) the type of approach (theoretical or empirical); (2) the theoretical influence of other fields of investigation; and, (3) the scientific disciplines involved. Therefore this first level led to three analytical axes, which we called *approach*, *field* and *domain*, respectively. The data analysis process to categorize articles in these three axes was reasonably straightforward, because these features are quite uncontroversial. In many cases, required information could be found in the abstract, but sometimes we had to turn to full papers to find it. Detailed explanations about these three axes are presented in the following section.

The second analytical level (and fourth axis) refers to our research question regarding model conceptions. This part required a much more interpretative analysis. In order to develop a framework of analytical categories, we performed a recursive process of reviewing data in a *bottom-up* approach, which Erickson (2012) calls analytic induction, or, as called by Corbin and Strauss (1990), the method of *constant comparisons*. With some preliminary ideas about models in mind, sketched from readings of previous model categorizations from science education literature and brainstormed in group discussions on the subject, we began looking for what authors referred to when they used the term *model*. Then we searched for patterns in how models were being conceived in the investigations, seeking broader similarities to form wider categories through the use of analytic induction. As we explored the material, we began to realize that the use of models and modelling in our library was very diverse and nuanced, and that previous categorizations were not fit to adequately capture all the cases of model conceptions. As a consequence, we had to merge together categories which have a shared core, so as to reach a concise and proper framework, suitable to analyze the whole corpus. This refinement procedure was carried out until the researcher no longer noticed such ambiguities and inconsistencies, which occurred after reading approximately 25% of the corpus. From then on, the rest of the analysis followed a top-down approach based on the formulated categories.

During the categorization process, we noted that several papers included a literature review, or some other section with a general overview on the different concepts of model in science education literature. Obviously, the fact that the authors included such a review does not mean they would use those concepts in their own approach; therefore, we did not consider these parts of the papers when classifying them regarding model conceptions. Instead, we based our classification on the meaning of model most strongly emphasized in the original contribution brought up by the authors in each paper. In theoretical papers, this was usually a concept of model defended by the authors; in empirical papers, we looked for what was called a *model* in practices and activities proposed and analyzed by authors. We opted for carrying out this coding process by ourselves, without resorting to data analysis software, due to the highly interpretative character of the model conceptions. Even though this option made the whole process much more time-consuming, we felt it was necessary, especially after examining a few papers and noticing how nuanced some occurrences might be, and how it would be problematic to assign categories directly to keywords or to try to automatize the categorization. Besides, the use of software for category analysis is contraindicated when the coding unit is large (BARDIN, 1997).

Validity

Lincoln and Guba (1985) suggested some measures to help increasing the probability of a study's trustworthiness in terms of implementing certain criteria, which are further discussed by Lodico, Spaulding and Voegtle (2006). Following the authors' suggestions, we ensured the researcher in charge of devising and applying the categories had a prolonged engagement and persistent observation regarding the corpus since she was the only person implementing all steps of data analysis described in the previous subsection, being involved in this substantial work for approximately eight months. Both prolonged participation of the researcher and persistent observation are suggested as ways to foster credibility (LINCOLN; GUBA, 1985). To promote dependability, we strove for providing a detailed description of data collection and analysis procedures (LODICO; SPAULDING; VOEGTLE, 2006) in the preceding subsection, as well as a thorough description of each analytical category, which is presented in the next section. Additionally, we included a few examples of occurrences in each category of model conceptions, so as to make our descriptions clearer and to help illustrate their pertinence. We have also explained any additional criteria used to assign papers to categories. Moreover, we made the data available for review, as proposed to reinforce dependability (LODICO; SPAULDING; VOEGTLE, 2006). To ensure confirmability, we implemented a confirmability audit (GUBA 1981; LODICO; SPAULDING; VOEGTLE, 2006) by using an intercoder agreement procedure, which was performed only in the part of the results that refers to the model conceptions (fourth axis), since this was the most interpretative, therefore more susceptible to trustworthiness threats. To this end, the second author independently coded 20% of all papers included in our corpus. To compare with the first author's categorization, we used Cohen's kappa, a statistical measure used to evaluate intercoder reliability when classifying items according to pre-established categories, which allows correcting the effect due to agreements reached by chance. According to Fleiss (1981), kappa values over 0.75 indicate an excellent level of agreement. In our procedure, the resulting value was 0.83, indicating a significant level of agreement over chance.

Findings and Results

Analytical axes

As previously explained, the analysis is organized in four axes, each corresponding to a specific aspect of the selected papers. In what follows, the axes are described and further criteria used in the categorization process are explained. Exactly one category from each axis was ascribed to each manuscript contained in the corpus.

1. **Approach**: this axis registered whether the study presented is of empirical or theoretical nature, as a whole. Naturally, empirical studies include theoretical considerations in some of their sections; however, all papers whose objectives and/or methodologies were based on empirical investigations were ascribed to the category *empirical*. Therefore, papers classified as *theoretical* did not develop empirical investigations by themselves at all (although they could, of course, include discussions about empirical studies found in the literature).
   - *Empirical*: as explained above, all papers presenting original investigations of empirical nature were included in this category. The most frequent cases found were studies analyzing the results of modelling activities and teaching practices based on modelling, focusing on a myriad of issues, such as learning outcomes, argumentation, views on the nature of science, among others. Research subjects could be both students and teachers. Textbooks analysis were also included in

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this category.

- *Theoretical*: this category comprises all other papers, that is, all those contributing exclusively with theoretical considerations. Most theoretical papers consisted of reflections upon the nature of models and modelling and their relevance to science education contexts, as well as guidance, recommendations and proposals on how models and modelling should be presented in such contexts.

2. **Field:** this analytical axis indicates fields of investigation that have been used as sources of inspiration or as theoretical frameworks, or that relate more closely to the approach of each article. For the purposes of this classification, we have separated the categories History of Science (HoS), Philosophy of Science (PoS), History and Philosophy of Science (HPS, when both fields were emphasized) and Economics of Science (EoS, which had only one occurrence) and Cognitive (encompassing studies that were based on frameworks from cognitive psychology, learning or development theories). Many articles, however, were not grounded on any of these areas; instead, they were theoretically based on other studies from the field of Science Education itself. In these cases, articles were categorized under this axis simply as *Science Education*.
3. **Domain:** manuscripts were classified in this axis according to the specific disciplines or subjects to which they related most directly. Sometimes authors do not refer to the discipline itself, but focus on a specific concept. In these cases, the manuscript was categorized according to the discipline closest to this concept (for example, articles that proposed to model friction were categorized as Physics). Cases where there is not even this kind of indication – such as those aiming at science education in general – or those that refer to science teaching in elementary school – where scientific subjects are usually not separate in different disciplines – have been categorized simply as *science*.
4. **Model Conceptions:** this is the most important axis since it pertains to the meanings assigned to models, either explicitly or implicitly. It was also the most complex aspect to categorize, because papers were quite heterogeneous and frequently would not explicit clearly what conception about the nature of models was being adopted by the authors. As a result, it required us to establish a few additional criteria. Firstly, as multiple conceptions about models could be discussed in the same paper (for example, when the authors presented literature reviews, or tried to contextualize their work), we have not considered all these conceptions stated on overviews or generic discussions; instead, we searched for the conception actually embedded in the original contribution brought forth in the paper. In addition, in some of the empirical papers, we noted that the conceptions about models discussed in theoretical sections might not match the ones actually incorporated in the instructional activities or in the data analysis. In such cases, conceptions were assigned based on the activity actually developed (or in the analysis performed on the empirical data, according to the case), since we were interested on how conceptions about models were effectively being used in educational practices and research.

- *Concrete*: studies considering models as visual schematic representations such as drawings, pictures, diagrams, flowcharts, maps, analog models, prototypes, three-dimensional physical models, gestures, simulations involving computational animations, non-mathematical computational simulations, scale models, representations using concrete materials and other iconic and pictorial representations of objects or processes, such as schematic diagrams of hydrologic cycling, blood circulation or the greenhouse effect. Concept-process models, in which the use of arrow flowcharts is central, were also included in this category. As an exemplary case of concrete models, Nelson and Davis (2012, p. 1932) stated "[...] models serve as visual representations of the students' understandings of the science being portrayed". Similarly, for Windschitl and Thompson (2006, p. 784),

> [...] scientists create models in the forms of analogies, conceptual drawings, diagrams, graphs, maps, physical constructions, and computer simulations as a means of describing and understanding the organization of systems, from cells to galaxies, and natural processes, from evaporation to predato-prey relationships.

The same meaning of model can be identified in Hoban, Loughran and Nielsen (2011, p. 989), in their didactical proposal: "[...] models made out of everyday materials, such as plasticine, cardboard, or paper, or use existing plastic models and take digital still photos of the models as they are moved manually".

- *Construct*: this category encompasses studies taking models as conceptual, approximative, idealized, simplified and abstracted representations of objects, events, phenomena or processes, expressible in terms of ideas about them. Creating this sort of models typically involves attributing certain properties to the targets so as to create conceptual counterparts of them, as well as developing hypothetical-deductive relations among these properties, sometimes trying to connect them with broader theories. Either way, models are taken as theoretical entities providing a conceptual, partial, abstract representation of their targeted phenomena which can, in turn, be used to produce new knowledge. Even though some modelling proposals classified under this category may include the use of some pictorial element or some equations, the emphasis is not placed on these, but on the *conceptual* (therefore, theoretical) nature of the representations. Studies under this category frequently are concerned with the relationship between models and their referents, stressing the approximative, abstracted and tentative character of these entities and their limited domain of validity. From an epistemological perspective, this category can be related to a wide scope of approaches about models in philosophy of science literature, such as Nersessian's "generic modelling" (NERSESSIAN, 2002), Koponen and Tala's "generative modelling" (KOPONEN; TALA, 2014), Mario Bunge's (BUNGE, 1973) theory of models, Cartwright’s (1983) position, Morgan and Morrison’s "models as mediators" proposal (MORGAN; MORRISON, 1999) as well as semantic views of theories (GIERE, 1988; SUPPE, 1977; SUPPES; 1962; VAN FRAASSEN, 1980), amongst others. Occurrences in which this category was identified in direct characterizations or definitions by the authors included assertions such as "[...] in the context of this study, a model in the broad sense is considered to be a simplified representation of a system, which concentrates attention on specific aspects of the system" (WILLIAMS; CLEMENT, 2015, p. 83) and

> [...] any theoretical model inherits the partial and idealized character of the model-object [...] theoretical models are tentative by nature, and they can agree approximately with empirical evidence at best. [...] theoretical models can be seen as mediators between theory and our ideas about reality. (MACHADO; BRAGA, 2016, p. 828).

Highlighting models' limitations, Jong, Chiu and Chung (2015, p. 990) designed "[...] a modelling-based text that emphasizes and explicitly presents the modelling sequence and its stages, including a specific focus on model validation and model reconstruction".

- *Mathematical*: studies using quantitative data to create or to evaluate models, to compare predictions or simulations to actual data, to explore the behavior of systems using mathematical tools (including computational simulations, provided these employ explicitly some kind of mathematical treatment), as well as mathematical representations in the form of equations, graphs, charts or other apparatus used to manipulate and control variables or to test the influence of certain variables in producing certain effects, with or without the use of softwares. In short, studies under this category refer to the term models as meaning mathematical models. In their investigation on how students reason and justify the mathematical formulation in experiments about electricity, Mäntyla and Hämäläinen (2015, p. 699) claimed that "[...] an understanding of how to navigate between phenomena and the models representing them in mathematical form is important for a physics teacher so that the teacher can make physics understandable to students". Such experiments were designed so as to allow for the establishment of quantitative laws relating current, voltage and resistance. In a similar approach, but using a simulation software, Singha and Loheide (2011, p. 548) based their proposal in the assumption that "[...] numerical modelling – meaning in this case the solving of differential equations in a 2-D or 3-D space by approximation with an algebraic system of equations – has been shown to be an effective bridge between scientific disciplines [...]". Schuchardt and Schunn (2016, p. 293) argued that "[...] it is possible to transform the use of mathematics for a particular topic from data presentation or calculated procedure to modeled process, rather than simply assuming that specific science topics require calculation or data summary approaches".

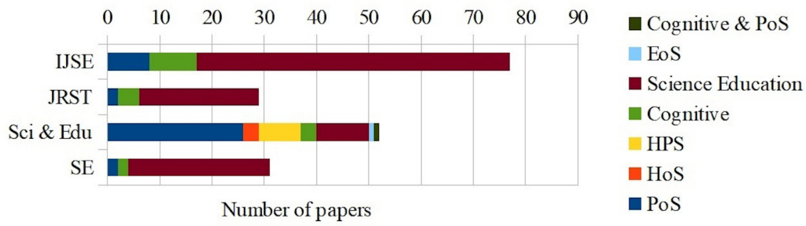
Results: approach, field and domain

Based on our criteria already described, a total of 189 papers were selected to constitute the corpus of the analysis. Among the journals investigated, IJSE had the highest amount of papers included (n = 77), followed by *Sci & Edu* (n = 52), SE (n = 31) and JRST (n= 29). Most of these papers (n = 161) were comprised of empirical studies, and only 15% (n = 28) focused on theoretical considerations. Among the theoretical papers, most of them were published in *Sci & Edu* (n = 25), encompassing almost half of all analyzed studies contained in this journal. Only two theoretical papers were found in IJSE, one in SE and none in JRST.

Concerning the fields of investigation providing contributions to the studies analyzed, *Science Education* predominated with 63% of all papers being related to this category (n = 120), while Philosophy of Science (PoS) had 20% (n = 38), followed by Cognitive studies (n = 18), HPS (n = 8) and HoS (n = 3). One paper was inspired by Economics of Science (EoS) and another was based simultaneously on Cognitive science and Philosophy of Science. This is certainly an expected result, considering that the theme of models and modelling has been extensively studied in Science Education research in past decades, therefore providing a solid enough framework to support new investigations autonomously. It also makes sense to find PoS and Cognitive studies as relevant sources of theoretical foundation, since both these fields are also engaged with discussions on the nature of models in science and in human thought in general.

In this analytical axis it was also possible to notice different inclinations according to the journal, as shown in Figure 1. Although the field of Science Education research predominated overall, in *Sci & Edu* this was not the case, with Philosophy of Science making up for half of the analyzed papers. Even though this journal also had proportionally more theoretical papers, most studies based on PoS were still categorized as empirical in nature (n = 23, around 60%). In addition, as shown in Figure 1, *Sci & Edu* was the only journal encompassing the less frequent categories, while the three main ones were enough to account for all occurrences in the other journals.

Figure 1 – Fields of influence according to the journal

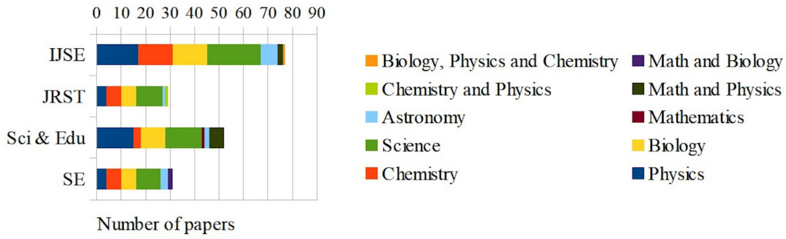


Source: prepared by the authors.

Regarding domains, as expected, Science was the most frequent, amounting to about 31% (n = 58) of all papers, as shown in Figure 2. This is certainly not surprising, considering this category covers all studies dealing with science education in general. But studies about models focusing specifically in Physics teaching were not far behind, representing 21% (n = 40), followed by Biology (19%, n= 36) and Chemistry (15%, n = 29). So it seems there is just a slight difference in the frequencies of the three main scientific disciplines. In addition, about 7% (n = 13) of papers highlighted models in Astronomy and there was only one dealing with modelling in Mathematics teaching. However, there were other papers discussing models and modelling focusing on Mathematics with some other domain: eight papers dealt with both Mathematics and Physics and two focused on Mathematics and Biology. One paper was occupied simultaneously with the fields of Chemistry and Physics and another congregated the three fields: Biology, Chemistry and Physics. These numbers indicate that, within the research concerned with an interdisciplinary approach to modelling in science teaching, studies whose focus converges Mathematics and Physics. This might be due to the nature of knowledge pertaining these domains, since Physics' mathematical structure is perhaps more evident. Overall, these results showed very few works dealing with interdisciplinary model construction in secondary and tertiary education.

Concerning the distribution of domains, there was no clear contrast when comparing the four journals.

Figure 2 – Domains according to the journal



Source: prepared by the authors.

Results: model conceptions

As previously described, our analysis allowed us to distinguish three broad categories of conceptions about models: Concrete, Construct and Mathematical. Construct models were slightly more frequent (about 44%, n = 84) than Concrete models (41%, = 79), both having significantly higher frequencies than Mathematical models, with 26 occurrences. Within the 10-year period analyzed, it was not possible to identify any time trend regarding prevalence of any category. Total number of occurrences also fluctuates, being around 19 papers per year on average (σ = 2,8). An interesting correlation can be observed between model conceptions and approach: as shown in Table 1, all cases of Concrete models were found in empirical papers. Possibly, part of the explanation lies in the fact that most papers were empirical ones. Yet this result was reached inductively, and there is no a priori reason for not having entirely theoretical papers arguing for teaching models as concrete entities (such as concrete analogous), at least in the context of our methodology. The fact that almost half of all empirical papers were based on this notion may suggest that authors implementing such modelling processes in the classroom tend to understand modelling as constructing visualization aids. This makes sense considering that the act of providing resources for visualizing certain phenomena would naturally require developing some empirical activity.

Table 1 – Model conceptions according to approach

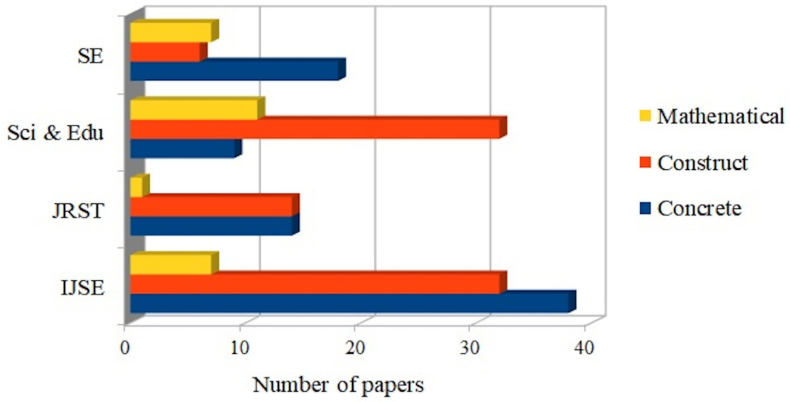
	Theoretical	Empirical	Total
Concrete	0	79	79
Construct	19	65	84
Mathematical	9	17	26
	28	161	189

Source: prepared by the authors.

When comparing model categories within the fields axis, two connections can be highlighted: among studies inspired by Philosophy of Science, most (71%, n = 27) hold the view of models as Constructs, while studies based on Cognitive frameworks are mainly related to the notion of models as Concrete elements (72%, n = 13). Whether such categories can be regarded as representative of the conceptions about models pertaining to each of these sciences, however, is beyond the scope of our study; all we can discuss about is how these notions are being appropriated in science education research related to models. In any case, the interconnectedness between models as Constructs and the contributions from Philosophy of Science could be at least partially foreseen in the examples we described when defining that category, since many of them consisted precisely in philosophical propositions.

The different scenarios regarding journals can be seen in Figure 3. The notion of models as Concrete entities predominated in SE (58%) and in IJSE (49%), although by a much smaller margin in the latter. In JRST, these categories had both the same number of occurrences (n = 14). However, in *Sci & Edu*, conceptions about models as Constructs were much more numerous than Concrete models (62% and 17%, respectively). This result is coherent with the previous analysis and reinforces the relatedness between the notion of models as Constructs and the influence of philosophical frameworks, since *Sci & Edu* stood out as the most inspired by Philosophy of Science regarding research fields.

Figure 3 – Number of papers of each model conception according to journal



Source: prepared by the authors.

Discussions and Conclusions

Among other findings, our analysis revealed that current research on models and modelling (1) is predominantly empirical in nature; (2) is founded in theoretical frameworks arising mainly from science education research itself, but is also considerably influenced by Philosophy of Science and studies from cognitive sciences; (3) encompasses physics, biology and chemistry domains in relatively similar frequencies, but decreasing in this order. Regarding model conceptions, we found different notions which can be represented in three main trends: Concrete, Construct and Mathematical. Although the polysemous character of the word *model* is already well known in the science education research field, this study allowed us to find other properties. As we sought to capture the meanings attributed to models and modelling in the reviewed articles, our categories ended up showing conceptions that, at first glance, may seem to go in opposite directions. While propositions labeled as Concrete models ultimately consist in providing ways to create and use material and pictorial forms of visualization of objects and events – therefore trying to make them more *concrete* – construct models, on the contrary, tend to emphasize the *abstract*, idealized, conceptual nature of models. In our understanding, these two trends can be seen as complementary. On the one hand, scientific concepts such as energy, species, cell, inertia, electrons, etc. are certainly idealized, abstracted entities, even though they are created in an attempt to represent real objects, properties and phenomena (BUNGE, 1973). On the other hand, external visualizations play a key role in human cognition and conceptualization, both in helping knowledge internalization and in its communication. Contributions of visualization to modelling-based teaching are richly discussed in Gilbert and Justi (2016).

Whether contradictory or complementary, the fact is that quite different ideas are being held under the same label of *model*, sometimes probably inadvertently. Throughout our analysis, we noticed that, very frequently, authors' conceptions about models were kept somehow implicit, with only a minority of papers explaining what exactly they believe a model is. Tala (2011, p. 734) even refuses explicitly to provide a conception altogether, since "[...] numerous attempts have shown that it is impossible to give a definition encompassing all the features of models and modelling". However, the idea that the failure to produce a single, universal definition of a model (assuming this is the case) exempts us from making explicit our conception of the term is deeply disputable. We agree with Kahn and Zeidler (2017, p. 538), for whom "[...] lack of conceptual clarity threatens construct validity, hampers theory development, and prevents science education researchers from focusing on the precise skills they wish to study and promote".

Another outcome of this study was the emergence of different scenarios regarding the journals consulted. These distinct patterns in research trends were not anticipated in our study design. Yet our findings showed that, while papers published in Science & Education had a tendency to consider models as Constructs, those from SE were much more inclined to communicate views of models as Concrete entities. In addition, the influence of other fields of research is different: particularly, studies on models published in *Science & Education* are much more influenced by philosophical frameworks than those in other journals. Even though these kinds of discrepancies might stem from features of these journals in general, not just their papers concerned with models, both the differences in general aspects of studies and in model conceptions found in our results point out the existence of different paradigms (KUHN, 1996) in the research community.

Considerations and Limitations

Like any study, ours has a number of limitations. First and foremost, it must be noted that the proposed model conceptions do not necessarily entail any commitment from the papers' authors with a single conception about the nature or purpose of models. Authors may hold different, wider conceptions or even have papers ascribed to distinct categories. That said, a major limitation is that our analysis applied one way to categorize the meanings assigned to models and modelling which was based on our own theoretical perspectives on the subject. Surely there could be several other ways to categorize this subject, from different points of view, and these would bring about different findings and insights. However, this is probably the case of any analytical study, at least to a certain extent, since no knowledge is built upon a theoretical vacuum. This limitation is perhaps more likely to be epistemological than methodological in nature. Finally, there is also another important limitation, which lies in the search method itself. Presumably, there can be studies dealing with models and modelling in science education without using these specific terms. For instance, they could be referring to *representations* or *simulations* instead, even though they might be actually discussing about models. Such cases would not be captured by our search mechanism. This also applies to occurrences of our search terms in fields other than the ones we have targeted. In these cases, there might be papers expressing certain views about the nature of models which would also not be captured by our search.

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