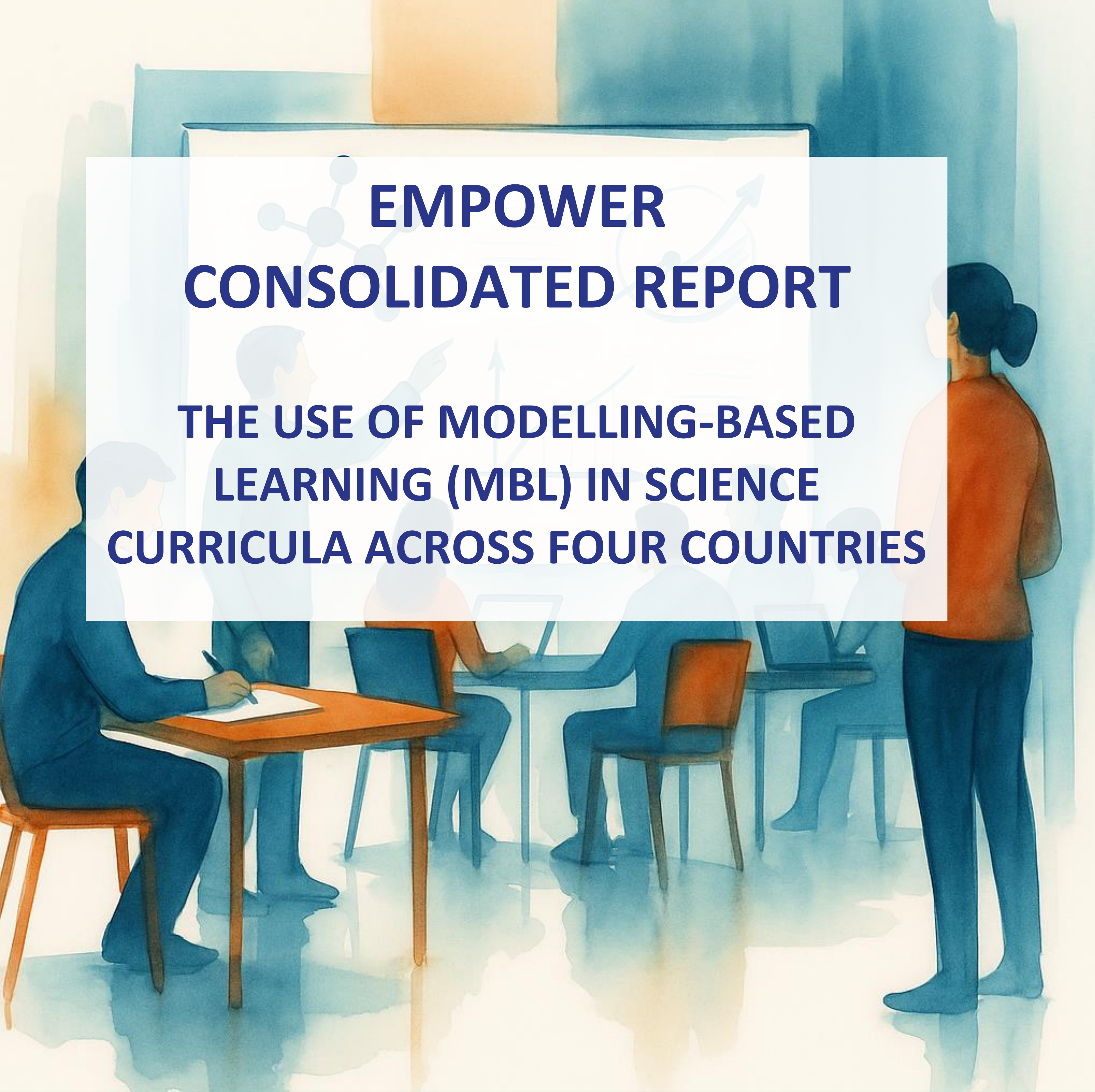

# EMPOWER CONSOLIDATED REPORT

## THE USE OF MODELLING-BASED LEARNING (MBL) IN SCIENCE CURRICULA ACROSS FOUR COUNTRIES

2026

EMPOWER

Empowering Teachers for Science Learning Through Modelling-Based Approaches

IPN | European University Cyprus | SOSCIEATH The Center of Excellence in Research & Innovation in Social Sciences, the Arts & Humanities | University of Cyprus | Radboud Universiteit | Utrecht University | UAB Universitat Autònoma de Barcelona | Co-funded by the European Union | Erasmus+ Enriching lives, opening minds.

# Erasmus+ Project EMPOWER

## EMPOWERING TEACHERS FOR SCIENCE LEARNING THROUGH MODELLING-BASED APPROACHES

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## Contents

# 1 Introduction

This consolidated report presents a comparative analysis of how modelling-based learning (MbL) is represented in science curricula across the four European partner countries: Spain (Catalonia), Germany, the Netherlands, and Cyprus. Drawing upon the national reports[1] produced within the EMPOWER project, the analysis aims to identify common patterns and trends, and key differences in the conceptualization and pedagogical treatment of MbL within formal curriculum documents. The participating countries in the project represent a diverse range of educational governance systems, from highly centralized systems such as Cyprus to decentralized and federal structures such as Germany and Spain, as well as a semi-centralized system with curricular flexibility, as in the Netherlands. These structural differences significantly shape how MbL is articulated, implemented, and supported within national curricula.

Across all analysed educational systems, science curricula emphasize core elements such as scientific inquiry, conceptual understanding, and real-world application. However, MbL is not consistently positioned within these frameworks; the extent to which MbL is framed as a distinct scientific practice, a core competence, or a supporting instructional tool varies considerably between the countries. In some contexts, it emerges as an explicit scientific practice tied to disciplinary thinking, while in others it remains embedded within broader inquiry processes or appears as a practical teaching tool linked to specific content topics. These differences reflect not only structural variations but also differing epistemological orientations towards science education.

# 2 Methodology

All national reports were based on qualitative content analysis guided by a shared coding framework developed within the EMPOWER consortium. This common analytical structure enabled systematic comparison across diverse curricular contexts, despite substantial differences in curriculum formats, scope, and educational structures. The analysis focused on identifying references to models, modelling practices, modelling competence, and related concepts across official curricular documents.

The corpus of analysed materials varied significantly across countries. In Germany, the analysis covered 67 curriculum documents from all 16 federal states, reflecting the decentralized nature of the education system, resulting in 1322 references to MbL. In Cyprus,

[1] While 4 different countries participate at the program Spain (Catalonia), Germany, the Netherlands, and Cyprus), the two partners from Cyprus have produced separate reports, focusing one on the primary education (ages 6-12) and the other on lower middle school biology (ages 12-15). Therefore, we have a total of 5 national reports.

both primary science and lower secondary biology curricula were examined through teacher guidebooks, resulting in 114 references in primary science education and in 215 references in lower secondary biology education. The Dutch report focused on the newly developed national core objectives, identifying 30 references to MbL, while the Catalan curriculum in Spain yielded only a small number (2) of relevant instances. Table 1 below summarizes the analysed materials.

**Table 1** *Curricular documents analysed*

| ***Country*** | ***Curriculum analysed*** | ***References identified*** |
|---|---|---|
| *Germany* | 67 biology curriculum documents from 16 federal states, student ages 5-11 | 1322, Average 19 references per state (minimum: 0, maximum: 97) |
| *Cyprus* | 9 curriculum documents, 6 for student ages 6-12 in elementary science, and 3 for student ages 12-15 in biology. | 114 (primary science)<br>215 (lower secondary biology) |
| *Spain* | 1 curriculum document for primary education (grades 1-6) | 2 (primary education) |
| *The Netherlands* | 1 curriculum document for primary education (grade 1-6) and 1 curriculum document for lower secondary education (grade 7 to 9). The analysis focused on the Humans and Nature[2] domain of the curriculum. | 5 (primary education)<br>25 (lower secondary education) |

The coding scheme captured multiple dimensions, including definitions of the modelling competence, the significance of models, types of models, contexts of use, modelling practices, meta-modelling knowledge, and instructional strategies. Each textual unit could be assigned multiple codes, and instances lacking sufficient detail were categorized as "not specified." Across all countries, a notable feature of the analysis was the frequent occurrence of unspecified categories, indicating a lack of explicit guidance in curricular texts. Table 2 below presents the analytical scheme used.

**Table 2** *Coding scheme used for the analysis of MbL references*

| ***Category*** | ***Sub-Category*** |
|---|---|
| *Definitions of modelling competence* | Specified |
| | Not specified |
| *Significance of models* | … in the natural sciences |
| | … in the educational process |
| | … in the modelling process in Science |
| | Not specified |

[2] This domain concerns the natural sciences and technology, their nature, and the interactions between humans and nature.

| | |
|---|---|
| *Types of models* | Mental |
| | Conceptual |
| | Physical |
| | Models available in the school lab |
| | Simple model |
| | 3D model |
| | Diagram |
| | Drawing |
| | Digital model |
| | Mental model |
| | 2D model |
| | Role play model |
| | Multiple models |
| | Not specified |
| *Contexts of model use* | |
| *Modelling practices* | Model creation |
| | Model use/selection of models |
| | Model evaluation |
| | Model revision |
| | Not specified |
| *Meta-modelling knowledge* | Knowledge about the properties and functions of models |
| | Knowledge of the modelling process |
| | Not specified |
| *Other* | Significance of Modelling-Based Reasoning |
| | Use of models to understand the concept of a Physical System |
| | Not specified |
| *Aim of text* | For the teacher |
| | For the student |
| *Ways/strategies of using MbL* | Ready-made models |
| | Ready-made models by other students |
| | Develop models from scratch |
| | Not specified |

# 3 Background

The structure of national education systems plays a critical role in shaping how MbL is represented within curricula. Germany's federal system leads to a diverse landscape of curricula across its 16 states, with coordination provided through common educational standards. The federal system leads to different types of schools across the German states and different approaches for how and when the science subjects are taught in an integrated way or as individual subjects (e.g., Biology). Spain similarly operates within a decentralized framework, although the Catalan curriculum remains aligned with national guidelines, particularly in science education. In contrast, the Netherlands combines national core objectives with significant autonomy at the school level, allowing teachers flexibility in implementation. Cyprus, by comparison, follows a highly centralized model in which detailed teacher guidebooks strongly influence instructional practices. The Ministry of Education in Cyprus has developed teacher guidebooks for each Natural Sciences unit in primary education and for Biology in middle school. These guidebooks support teachers in translating the curriculum into classroom practice by outlining suggested lesson structures, learning objectives, content areas, classroom activities, materials, worksheets, and assessment opportunities.

# 4 Findings

## 4.1 Strategies for using MbL

*Across all countries, the analysis reveals a general lack of explicit articulation of teaching strategies for implementing MbL.* In Germany, 80% of references fall into the "not specified" category, indicating that the analyzed documents do not provide detailed guidance on how MbL should be integrated into teaching practice. In Cyprus, 27% of the references do not specify the MbL strategies being employed. In the Spanish case, no explicit strategies were identified. In the Netherlands, the absence of prescribed strategies reflects a deliberate design choice, as the curriculum leaves significant flexibility to schools and teachers.

When strategies are specified, ready-made models are the most frequently mentioned approach across both primary and secondary levels, particularly in Cyprus (46.5%) and Germany. Model construction from scratch is also present, especially in Cyprus (39%). However, the use of peer-generated models is almost absent. *Overall, the findings suggest that curricula tend to prioritize the use of models rather than clearly defining pedagogical approaches for MbL.*

## 4.2 Definitions of modelling competence

*Across all countries, there is an absence or minimal presence of explicit definitions of modelling competence.* In Germany and Spain, no such definitions were identified. In Cyprus, only about 3% of the references provide definitions. In the Netherlands, while the curriculum includes definitions of models and modelling, it does not frame these as part of a clearly defined competence structure. *This general lack of definition indicates that MbL is not conceptualized as a distinct scientific competence within curricula.*

## 4.3 Significance of models in the natural sciences

*The significance of models is only partially articulated in the analysed curricula, and in many cases, it remains implicit.* In Germany, references to the importance of models account for the 8% of the total codes, and in Cyprus, about 21% of references explicitly specify the role of models within science. The Spanish curriculum does not provide explicit statements regarding the epistemic role of models, while in the Netherlands, models are described functionally as tools for understanding and explaining phenomena, without extensive discussion of their scientific significance. *Overall, models are primarily framed as tools for representation and explanation, rather than as central epistemic constructs in the development of scientific knowledge.* This suggests that the deeper role of models in scientific reasoning is not systematically addressed in most curricula.

## 4.4 Types of models

*The analysis reveals a wide range of model types across countries, although their explicit identification varies considerably.* In Cyprus, physical models dominate, particularly in primary education (44%), where they are frequently used to represent observable scientific phenomena. In lower secondary education, both mental (48%) and physical models (32%) are prominent. The German curricula also reference 5 clusters of model types, with functional (25%) models being the most prominent one. The Dutch curriculum also provides an extensive list, including digital, analogue, conceptual, and disciplinary models such as particle and climate models. In contrast, the Spanish curriculum does not explicitly identify model types.
*Despite this diversity, a large proportion of references remain unspecified in all countries, limiting the clarity of expectations regarding the kinds of models students should engage with.* As a result, the range and progression of model types are not always systematically articulated.

## 4.5 Contexts of model use

*Models are employed across a wide range of scientific contexts, reflecting the content structure of each curriculum.* In biology-focused curricula, such as those of Cyprus and Germany, MbL is closely linked to topics such as cells, human physiology, and ecological systems. In primary education contexts in Cyprus, MbL is frequently associated with topics such as Earth and sky, electricity, and the human body. In the Netherlands, MbL appears across broader scientific domains, including physical systems, chemistry, and Earth sciences. In Spain, although MbL is not explicitly emphasized, it can be inferred in relation to key scientific ideas such as ecosystems and energy systems.

## 4.6 Modelling practices

*A consistent pattern across countries is the dominance of model use over other modelling practices, such as creating, evaluating, or revising models. Students are most often expected to use, while opportunities to engage in model creation are present but less frequent.* Practices such as model evaluation and revision are significantly underrepresented. In Germany, model use accounts for the 66% of modelling practices, while revision is almost completely absent

(2%). Model creation is 19%, and model evaluation is 13%. In Cyprus, a similar distribution is observed, with model use (about 42%) and creation (23%) dominating, and evaluation (10%) and revision (10%) occurring only sporadically. In Spain, only model creation is explicitly mentioned, whereas in the Netherlands, all aspects of the modelling cycle are present, at higher educational levels. *These results indicate that some curricula do not support the full modelling cycle,* potentially limiting students' opportunities to engage with modelling as an iterative and reflective scientific process.

## 4.7 Meta-modelling knowledge

*Meta-modelling knowledge is the least developed dimension across all countries.* In Cyprus, the majority of references do not address meta-modelling explicitly (87%). In Germany, only limited attention is given to the nature and function of models (7%), while in Spain, such references are absent. The Netherlands analysed documents include explicit references to both the properties and limitations of models, particularly in more advanced educational tracks. *Where meta-modelling knowledge is addressed, it primarily focuses on understanding models as representations, rather than on understanding the modelling process itself.* This suggests that the curricula analysed do not actively address the development of a reflective understanding of modelling as a scientific practice.

## 4.8 Aim of the curricular text

*Across all countries, most references to MbL are directed toward students (rather than only the teachers), emphasizing modelling as part of the curricular text.* In Cyprus, approximately 63% of references are student-oriented, with the remaining 37% directed at teachers. Similarly, in Germany, 39% of the MbL references are directed to teachers and the 61% to the students. In the Netherlands and Spain, references are almost exclusively framed in terms of student learning outcomes. This indicates that MbL in the analysed curricula is presented primarily as an activity for students, although the extent of pedagogical guidance provided to teachers varies.

# 5 Conclusions

The cross-national analysis reveals that MbL is present across all examined curricula, yet it is not consistently developed as a coherent or explicit component of science education. In most cases, MbL appears as an implicit element within broader inquiry processes rather than as a clearly defined scientific practice. The absence of explicit definitions of modelling competence further contributes to this lack of conceptual clarity.

Across countries, there is a clear emphasis on using models, while other important aspects of modelling, such as evaluation and revision, are less frequently addressed. This imbalance suggests that students may have limited opportunities to engage with the full MbL cycle and to develop a deeper understanding of the epistemic role of models in science. Furthermore, the limited attention given to meta-modelling knowledge indicates that curricula do not sufficiently support reflective understanding of the nature and purpose of models.

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