The Perception of Technological Models among Upper Secondary School Students

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Abstract

Globally there is rising interest for introducing engineering education as part of general secondary education. Across Europe in particular, several curricular reforms and policy initiatives have emphasized the integration of engineering concepts into general secondary education as part of broader STEM agendas (Moore et al., 2014; European Commission, 2015; Kelley & Knowles, 2016; Nia & de Vries, 2017; Demirci & Özyürek, 2024; Ahmad et al., 2026). Such developmental trends reflect a growing recognition that engineering literacy is relevant for all students, not just those pursuing technical careers. Consequently, understanding how students conceptualize central constructs within engineering education, such as technological models, becomes increasingly important. Given that technological models is a central construct in engineering education (Rossouw et al, 2011), the impetus for this research was to establish a baseline regarding perceptions of the technological models construct held by students at the upper secondary level.

The research presented in this article followed a mixed method design implemented within two international schools engaging a total of 345 students from 13 language backgrounds. Qualitative data were collected from 72 students through written and interview responses to questions asking participants to describe what they think a technological model entails. Quantitative data were subsequently collected from 338 students through a questionnaire consisting of 30 True/False items asking them to indicate if the picture in the item corresponded to their concept of a technological model. A factor analysis was carried out to reveal the dimensions of the concept among the students. Findings indicate that in contrast to previous studies among lower secondary school students, a distinct concept of a technological model was found among the secondary participants in this study. Furthermore, differences in model concepts held by male and female students at the lower secondary level revealed by prior research, were not found among the secondary level students in this study. Based on findings, the study revealed that the concept of technological models held by secondary level students indicated a reasonably correct understanding, although predominantly visual and product-oriented.

Key words: Concepts, technological models, engineering, higher secondary education

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Introduction

In Technology Education, both skills and corresponding concepts such as systems, functions, and models (Rossouw et al, 2011) should be the intent of instruction (Bellanca & Brandt, 2010). To design instruction that will adequately connect skills and concepts, educators would first assess preconceptions held by their students. Considerable research has been conducted regarding the assessment of preconceptions held by students of models in science education (e.g., AAAS, 2001; Grosslight et al., 1991). In stark contrast, empirical research explicitly addressing preconceptions held by students of technological models in engineering and technology education remains comparatively limited (e.g., Nia & de Vries, 2017).

Learning about concepts logically should be started in junior high school, but there are more opportunities in senior high school given students at that grade level are generally better able to think abstractly. Creating sound instructional materials for teaching engineering in upper secondary schools requires first carefully examining the concepts and abstract imagery students currently hold regarding key targeted learning outcomes for the subject (Rossouw et al., 2011). In engineering education, one key learning outcome is having students develop a reasonably correct understanding of technological models. To address this initial step in instructional design, the current study was conducted to ascertain preconceptions of technological models currently held by students in upper secondary education. The definition of a technological model adhered to in this study is *a representation constructed to support the analysis, design, prediction, optimization, or communication of a technological system*.

The current study was conducted in two European international secondary schools with linguistically and culturally diverse student populations. These schools follow harmonized curricula attracting students from multiple national backgrounds, which may influence students' prior exposure to engineering concepts and technological systems. While this context provides a heterogeneous sample, it may also introduce specific contextual characteristics that should be considered when interpreting the findings. Within this context, the aim of this research was to ascertain the preconceptions of technological models held by high school students prior to these concepts being introduced in the engineering curriculum. Understanding these preconceptions is crucial given the growing interest in many countries for integrating engineering into secondary education as a means to enhance technological literacy. By aligning the design of instruction based on an accurate assessment of student preconceptions, we can better ensure that the introduction of engineering concepts will be pedagogically sound.

Literature Review: Perceptions of Models and Modelling in Science and Engineering

Scientific Modelling

According to Gilbert (2004), models and the process of modeling are central to making science education more authentic and meaningful. Students should recognize that models can serve different purposes and come in diverse forms, including physical models, diagrams, formulas, and maps. Gilbert emphasizes that models in science are not exact copies of reality but tools that help explain and predict phenomena. Specifically, their primary function is not to serve as an exact replica, but to instead play various roles, such as facilitating communication, enabling experimentation, and enhancing understanding. In addition to their roles in understanding and experimentation, Gilbert suggests models can be categorized into five different representational modes: the concrete or material, the verbal, the symbolic, the visual, and the gestural. This variety of functions and representations highlights the broader role of models beyond simple replication.

A substantial body of research has examined the teaching and learning of specific scientific models, including particle models (Hitt & Townsend, 2015), molecular models (Treagust et al., 2002), and atomic models (Justi & Gilbert, 2002). In contrast, fewer studies such as that conducted by Grosslight et al. in 1991 have focused explicitly on students' understanding of the modelling process itself or on students' broader conceptions of models and their epistemological status in science (Grosslight et al., 1991). The students in the latter study often held views that corresponded to a simplistic epistemology. That is, the students usually regarded models as exact copies of reality, albeit on a different scale. However, the older students appeared to understand, that models are designed for specific purposes, and that a model may change over time, for example when new empirical data are analyzed. The functions of models in explaining and predicting observable phenomena were rarely recognized by these students (Van Driel & Verloop 2002).

In the science field of physics, the core of modelling is making approximations. This comes up regularly in lessons about gravitational fields. For example, a statement such as "in this problem you can neglect the air resistance" presents an approximation of the conditions that would actually exist. The use of models can take into account such approximations when attempting to solve complex problems such as those involving systems building on knowledge from different technological fields to understand and analyze each part of a system, how that part works, and how it interacts with other parts. This method of examining and solving a problem also presents the opportunity to take into account the relationships between other business areas, such as finance, sales or stakeholders, in order to efficiently understand and manage the entire system throughout the product lifecycle.

Modelling in Engineering

Using and creating simplified representations of reality is a fundamental aspect of modelling in general. Students learning to model often use a variety of representations to express, test, revise, and interact with their own thinking. Accordingly, the construction of models often depends on the fluency of the representation and the ability to translate between and within different kinds of representation.

Modelling in engineering takes on additional specific characteristics, often requiring a high degree of precision and accuracy, as they are used to predict the behavior of complex systems (Lammi, et al., 2020) under various conditions. These models must account for practical constraints such as material properties, safety factors, and regulatory standards. Moreover, engineering models are frequently used to optimize designs, ensuring that solutions are both feasible and efficient. This practical application necessitates a thorough understanding of the underlying physical principles and the ability to apply these principles in a variety of real-world scenarios.

The role of models and modelling in secondary technology and engineering education is crucial for helping students grasp the complexity of technological systems. Their role emphasizes that student engagement with models in engineering is essential for developing the skills needed to manage real-world design challenges, where precision, feasibility, and efficiency are key considerations (Norström & Hallström, 2023). By distinguishing these aspects, it becomes clear how the general principles of modelling are applied and expanded within the field of engineering. While models are used across the fields of both technology and engineering, engineering is a specialized field within technology that focuses on the development and optimization of systems and solutions. In engineering, models are designed to predict systems behavior under specific conditions, ensuring precision and functionality in practical applications. This professional focus on development and optimization requires the use of models that are both precise and quantitative in guiding the creation of real-world solutions.

Given the integral role of modelling in the fields of both science and technology and engineering, there is a growing need to create teaching materials that emphasize the core objectives of technological literacy. Modelling is an essential component of this literacy, and it must be framed in a way that highlights its importance in both the conceptualization and development processes within technology and engineering contexts (Norström & Hallström, 2023). Previous studies have also emphasized the critical role of models in these contexts, including foundational work by Gilbert et al. (2000), France, Compton, and Gilbert (2011), Haglund and Strömdahl (2012), and Nia and de Vries (2017). These studies offer key insights into the use of models for enhancing understanding in both technology and engineering education, underscoring the need for continued focus on this area in educational research.

Conceptual Distinction Between Scientific and Technological Models

Although modelling is central in both science and engineering, scientific and technological models differ in epistemological orientation and educational function. In science education, models are typically used to explain, predict, and represent natural phenomena and are often evaluated in terms of explanatory coherence and predictive adequacy (e.g., Gilbert, 2004; Grosslight et al., 1991). In contrast, technological models are embedded in design-oriented practices: they are used not only to represent existing systems, but also to guide the development, optimization, and realization of artefacts and technological systems under practical constraints (e.g., France, Compton, & Gilbert, 2011; Nia & de Vries, 2017; Wells, 2021). This distinction is pedagogically important. Students may encounter scientific models primarily as explanatory representations, whereas technological models may appear as drawings, schematics, prototypes, simulations, process models, and planning artefacts that support design decisions and production processes. Because technological models can have both representational and operational functions, students may hold a narrower *product-like* view of models and may fail to recognize abstract representations (e.g., equations, processes, schedules) as models within engineering contexts.

In this study, to clearly distinguish technological models from scientific models, we define a technological model as a representation (physical, graphical, symbolic, or procedural) that is purposefully constructed to support the analysis, design, prediction, optimization, or communication of a technological system and/or artefact. This definition aligns with accounts of models in technology and engineering education that emphasize their dual nature as both representational and action-guiding artefacts (Wells, 2016; Nia & de Vries, 2017).

Research Problem

Modelling is widely recognized as a central epistemic practice in both science and engineering (NGSS Lead States, 2013; Ford, 2015; Schwarz et al., 2022; Yesilyurt et al., 2024). Contemporary research emphasizes that modelling involves explanation, prediction, and design-oriented reasoning rather than merely the use of representations (Schwarz et al., 2017; Hallström & Schönborn, 2019). In engineering contexts specifically, models function as tools for iterative design, optimization, and decision-making, which differentiates them from purely explanatory scientific models. However, the extent to which modelling is explicitly taught as a structured and reflective practice varies across subjects and educational contexts. Although models are frequently used in classrooms, explicit attention to the epistemological and methodological dimensions of modelling remains uneven in secondary education (Svoboda & Passmore, 2013). This suggests that the didactic knowledge required of educators to support modelling as a core practice continues to develop. However, to date,

comparatively few empirical studies have explicitly examined students' conceptions of technological models in engineering and technology education, although interest in this area has increased in recent years (e.g., Nia & de Vries, 2017).

Research Goals

The main goal of our research was to identify the conceptions upper secondary students hold regarding technological models, building on our investigation of their preconceptions. In addition to understanding their existing perceptions, we sought to explore which factors influence the development of these concepts over time. The secondary goal is to continue developing comprehensive insights into conceptual understandings of technological models held by students before introducing these concepts into the curriculum. By examining background variables such as gender, language group, and the presence of Science, Technology, Engineering, and Mathematics (STEM) subjects in the curriculum, we aimed to uncover how these factors contribute to shaping the conceptions of technological models held by students.

Method

Research Design

This study is grounded in a pragmatic mixed-method orientation. Ontologically, we treat students' conceptions of technological models as context-dependent understandings that are shaped by educational experiences and language/curricular contexts. Epistemologically, the qualitative component adopts an interpretivist stance aimed at reconstructing how students articulate and explain their conceptions. Conversely, the quantitative component adopts a post-positivist stance aimed at identifying patterns and associations within student responses across subgroups. The overall theoretical lens is conceptual change and modelling-as-practice, which guided the development of the qualitative prompt, the construction of questionnaire items, and the integration (triangulation) of qualitative themes with quantitative factors. The study followed an exploratory sequential structure: the qualitative component was conducted and analyzed first and informed the construction of the questionnaire, after which the quantitative component was administered to a larger sample and the two strands were integrated through triangulation.

Participants

To investigate the conception of technological models held by students, the upper secondary school technology and engineering program was deemed a logical starting point as they require more knowledge of scientific concepts, principles, and mathematics than what students obtain throughout their lower secondary school education. A total of 345 students took part in the research, all of whom were in the first year of upper secondary education (approximately 15-

16 years old), which corresponds to the beginning of pre-university specialization within the European school system (Baird et al., 2017). Of these, 72 students (36 girls and 36 boys) participated in the qualitative component of the study by writing essays and taking part in interviews, and 338 students (155 girls and 183 boys) completed the questionnaire; 65 students participated in both components. To be consistent with previous studies conducted by the authors having an international focus (Köycü & de Vries, 2016), this study was also international based on the participant population, allowing for a more comprehensive insight into student understandings of technological models.

Data Collection

Qualitative

The goal of the exploratory qualitative component of the study was to gain a deeper understanding of how students conceptualize technological models through analysis of written essays and responses during semi-structured interviews. In both cases the same open-ended question (What do you think a technological model entails?) was posed to explore student conceptions of technological models. Essay and interview responses were collected simultaneously, and within the same instructional period to ensure student conceptions were captured within a consistent contextual frame. Written essays were completed individually by the 72 participating students (36 girls and 36 boys) during regular class time under teacher supervision. Semi-structured interviews were subsequently conducted with all 72 of these students to clarify and deepen interpretations emerging from the written responses. The gender balance of this group was deliberately chosen to allow the qualitative data to reflect the views of girls and boys equally.

All data collection was conducted by the first author in collaboration with the classroom teacher to ensure procedural consistency. Interviews followed a predefined protocol to enhance reliability, and student responses were audio-recorded and transcribed verbatim. The written responses were collected in digital form. To ensure fidelity of implementation, all students received identical instructions, and no evaluative feedback was provided during data collection to avoid influencing responses.

The use of both written responses and interviews allowed for methodological triangulation. Written essays enabled students to articulate their individual conceptions independently, while interviews provided opportunities to clarify meanings, probe ambiguities, and explore underlying reasoning in greater depth. Combining both methods strengthened the validity of the qualitative findings.

Quantitative

To investigate the students' understanding of technological models quantitatively, we developed a questionnaire designed to assess the extent to which student perceptions aligned with the concept of a technological model as presented in the statements provided. The questionnaire was comprised of 30 True/False statements, asking students to determine whether each provided item (a picture) corresponded to their concept of a technological model.

The use of a binary (True/False) format allowed for clear categorization of responses and facilitated factor analysis; however, it also limits the degree to which nuanced understanding or uncertainty can be captured. Students were required to make a categorical judgment, which may have oversimplified more complex or tentative conceptions of technological models. Future research could benefit from incorporating Likert-scale items or open-ended follow-up questions to allow for more differentiated expressions of understanding.

We developed these thirty items based on the essays and interviews obtained in the qualitative part of this study, as well as insights from previous research on models, particularly in the fields of both science and engineering. To strengthen content validity, the items were reviewed by two colleagues with expertise in technology and engineering education prior to administration. Minor wording adjustments were made to ensure clarity and conceptual alignment. While much of the foundational research on models has been conducted in science, where models function primarily as tools for representation and explanation, it is important to acknowledge that models in engineering often differ in their focus. Engineering models are typically more precise and quantitative, designed to predict system behavior and guide practical applications.

By integrating insights from both fields, we aim to provide a more comprehensive understanding of how models can be used effectively in various educational contexts. The inclusion of items related to process models stemmed from the desire to investigate whether students perceive various types of models, including process models, as examples of technological models. The items (pictures) were presented, and the students had to indicate whether the pictured object was an example of a technological model. The use of pictures was considered necessary because the study aimed to examine students' spontaneous recognition of technological models based on visual representations rather than on abstract verbal definitions. Visual stimuli enabled students to respond to representations commonly encountered in technological and educational contexts.

The selected images were deliberately chosen to represent a range of model types, including scale models, schematic diagrams, symbolic representations (e.g., equations), process models, and representations of final products. The selection was informed by literature on modelling in science and engineering education (e.g., Gilbert et al., 2000; Nia & de Vries, 2017) to ensure conceptual

diversity and alignment with established categories of models. Moreover, because we were interested in investigating differences between ideas of subgroups of students, we added some background variables that proved to be important in a previous study that dealt with the overall concept of engineering (Köycü & de Vries, 2016). For this study, we selected gender, language group (groups of students in two international schools divided by their primary language) and the presence of a school subject on engineering in their curriculum. We aimed to find out whether these background variables have an influence on the choices students make about what would be a technological model, or would not. The questionnaire was administered electronically over a five-month period, with students requiring approximately 10 minutes to complete. The following is a list of example model items:

- *A model airplane*
- *A Kirchhoff circuit*
- *A physics formula*
- *A graph*
- *A three-dimensional plan of a house*

Each item was displayed separately, and respondents could indicate with *True* if they thought it was a technological model and with *False* if they thought it was not a technological model. Additionally, we included questions probing the functions of models and requested explanations to gain insight into how students perceive the purpose and utility of technological models. These questions aimed to provide a comprehensive understanding of student perceptions and interpretations of technological models, including insights into their conceptualization, functions, and practical applications.

The questionnaire was administered to students enrolled in two international schools located in Luxembourg. These schools were selected through pragmatic access within an existing professional network, a form of convenience sampling commonly applied in educational research (Cohen, Manion, & Morrison, 2018). At the same time, the international and multilingual structure of the schools provided access to a culturally diverse yet institutionally comparable student population.

We acknowledge that this sampling strategy limits the generalizability of the findings. And therefore, although the schools operate within harmonized curricular frameworks, differences in prior exposure to engineering concepts and cultural attitudes toward technology may have had an influence on student responses. The findings should therefore be interpreted as context-bound rather than universally generalizable.

The decision to conduct the research electronically was made to streamline data collection and processing, which has been shown to reduce costs and minimize data entry errors (Wright, 2005). By utilizing electronic platforms, such as online surveys or data collection software, the questionnaire could be

easily distributed to a large number of participants while maintaining data integrity (Dillman, Smyth, & Christian, 2014).

With the assistance of colleague teachers from the participating language sections, the questionnaire was administered to 338 secondary school students (155 girls and 183 boys), 65 of whom had also taken part in the earlier qualitative component. Table 1 shows the number of participants per language group. The data collected included not only responses to the questionnaire items but also background variables such as gender, language group, and the presence of STEM subjects in the curriculum. These variables were included to explore potential correlations between students' understanding of technological models and their demographic or educational characteristics (Bryman, 2016).

Table 1

Participants per Language Groupings

Participants	
Language	***n***
Bulgarian	6
German	42
English	37
Spanish	48
Estonian	3
Finnish	16
French	70
Latvian	4
Lithuanian	5
Dutch	29
Polish	22
Portuguese	29
Swedish	27
Total	338

Data Analysis and Results

In this section, the results of the qualitative component and of the quantitative component are presented separately, followed by the triangulation of the two strands. The qualitative component comprised essays written by, and interviews conducted with, 72 students (36 girls and 36 boys). The quantitative component comprised questionnaire responses from 338 students (155 girls and 183 boys), 65 of whom had also participated in the qualitative component.

Qualitative Analysis and Results

Participants and Procedure

The essays written by participants were not regular classroom assignments but were specifically designed as research instruments for this study. A total of 72 students (36 girls and 36 boys) responded to an open-ended prompt about their understanding of technological models during scheduled class time, and all 72 students subsequently took part in a semi-structured interview. All participants were informed that their responses would be used for research purposes, participation was voluntary, and anonymity was ensured.

Analysis Procedure

The essays were analyzed using qualitative content analysis rather than documentary analysis of pre-existing classroom artefacts, as the texts were generated specifically for data collection within this research project. To identify key themes and keywords through content analysis of essay and interview responses, we used IBM SPSS Text Analytics and NVivo. This approach allowed us to develop a more comprehensive understanding of the students' ideas regarding technological models through both written and spoken responses. Through thematic analysis, each essay was carefully examined to identify passages or sections that addressed the concept of technological models. These relevant passages were then coded, assigning labels or categories to represent the underlying meanings or ideas conveyed. The coding process involved systematically organizing the coded passages into broader categories or themes based on similarities in meaning or content. The process of analysis was conducted as follows:

1. Data Coding: Essays were imported into NVivo, where text segments related to model descriptions were systematically coded. This involved identifying and labeling excerpts where students discussed different types of models.
2. Category Formation: Using NVivo's coding framework, we grouped these codes into broader categories based on common themes and characteristics identified in the students' descriptions. The four main categories emerged as: Schematic Representation Concept, Scale Model Concept, Number Sequences and Graphs Concept, and Functional Representation Concept.
3. Categorization and Analysis: Each category was further refined by reviewing the coded data for consistency and relevance. NVivo's querying tools were used to examine patterns and frequencies within each category, ensuring that the categorization reflected the students' conceptual understanding accurately.
4. Validation: To ensure robustness, the categorization was cross-checked by three colleagues. Any discrepancies in coding or categorization were discussed and resolved to achieve consensus.

Keywords and Concept Categories

The keywords identified through the qualitative content analysis process provide insights into the breadth and depth of students' understanding of technological models. Table 2 presents the keywords identified in the students' essays and interviews, grouped by the four concept categories that were subsequently derived from them.

Table 2

Keywords identified in students' essays and interviews, grouped by concept category

Concept Categories			
Schematic Representation	Scale Model	Number Sequences and Graphs	Functional Representation
map	mini car	source code	Kirchhoff circuit
floor plan	model plane	graph of movement	physics equation
2D model	prototype	graph of nuclear decay	applet
atom model	3D model of a house	graph of Ohms law	production process

Note. In addition to the keywords listed above, more general modelling terms such as scheme and representation, as well as keywords including reaction formulas, AutoCAD drawing, miniature, flowchart, production schedule, and simulation, occurred in the students' responses.

These keywords encompass a range of representations and applications of technological models as articulated by the students. While some keywords, such as schemes and representation, capture more general concepts related to modelling, others, like scale model and reaction formulas, represent specific types or forms of technological models. The keywords listed in Table 2 are not exhaustive but rather indicative of the diversity of ideas expressed by the students. The inclusion of both general and specific keywords reflects the multifaceted nature of technological models as perceived by the students. For example, the presence of keywords like floor plan and AutoCAD drawing highlights the students' recognition of various visualization techniques used in modeling, while terms like prototype and reaction formulas underscore their understanding of modelling in practical and theoretical contexts, respectively. By providing this overview of the keywords identified in the qualitative analysis (Table 2), we aim to offer a nuanced understanding of students' perceptions and conceptions of technological models as revealed through their essays. By comparing all the keywords in the essays, we were able to derive main categories of keywords. Of course, this method of coding is never entirely independent of existing ideas about technological models under study.

The following four categories emerged from the qualitative analysis. Although the categories were derived inductively from students' responses, their interpretation was informed by established distinctions in modelling literature, particularly between representational, symbolic, procedural, and design-oriented models (Gilbert et al., 2000; Hallström & Schönborn, 2019). The categories therefore reflect both empirical clustering in the data and alignment with existing theoretical perspectives.

1. Schematic Representation Concept: Includes models used as schematic representations of objects or ideas, such as maps, floor plans, and 2D models. These models provide an abstract representation of reality, as described by students in their essays.
2. Scale Model Concept: Encompasses physical or virtual scale models of objects or systems, including mini cars, model planes, and 3D models of houses. These models serve as simplified or scaled representations, reflecting their descriptive use by students.
3. Number Sequences and Graphs Concept: Includes models that use mathematical or graphical representations, such as graphs of movement, graphs of nuclear decay, and mathematical equations. Students' descriptions highlighted these models' roles in illustrating numerical data and trends.
4. Functional Representation Concept: Comprises models representing functional aspects of systems or processes, such as source code, applets, and production processes. These models focus on the operational or symbolic aspects of systems, as described in the students' essays.

The use of NVivo facilitated a structured and detailed analysis of the essays, enabling us to identify and categorize the conceptualizations of models effectively. This approach provides insights into students' understanding of technological and mathematical representations and serves as a foundation for evaluating their comprehension of these concepts. However, technological and non-technological models were often mixed in students' descriptions, indicating that they struggled to distinguish between the two. This suggests that students do not consistently distinguish between models used within technological design contexts and models originating from scientific or mathematical domains. In this study, a technological model is defined not by its form (e.g., diagram, equation, or scale model), but by its functional role within processes of technological analysis, design, optimization, or decision-making. From this perspective, certain models may function as *loan-models* when concepts or representations from science or mathematics are appropriated for technological purposes. The distinction therefore lies not in the disciplinary origin of a model, but in its intended use within technological practice. Addressing this confusion is essential to help students develop a clearer understanding of the role and nature of technological models in engineering contexts.

Student Recognition of Model Types

The recognition of models as schematic representations of reality among students was evident from the study's outcomes. Specifically, a substantial proportion of students identified 2-D models, 3-D models, Kirchhoff circuits, and miniatures as technological models. This recognition suggests that students may perceive these models as abstractions or simplifications of real-world systems or objects. This interpretation is supported by students' written explanations, in which they frequently referred to models as copies, scaled versions, or representations of something that already exists. Such descriptions indicate a representational rather than a functional or design-oriented understanding of models. To elaborate, a model, in the context of engineering education, serves as a simplified representation of a more complex reality. For example, a 2-D model might depict a cross-sectional view of an object, while a 3-D model provides a spatial representation. Kirchhoff circuits illustrate electrical principles through schematic diagrams that abstract the real-world behavior of electrical systems. Miniatures, on the other hand, offer scaled-down representations of objects or systems, making complex structures more comprehensible. The ability of students to classify these various forms of models as technological representations indicates an understanding that these models, despite their simplifications, capture essential features of the systems they represent. This understanding aligns with the concept of models as tools for bridging the gap between theoretical concepts and practical applications. In their essays and interviews, students also mentioned real products among their examples of models (*I see real products as models we can analyze.*).

However, it is important to note that while students were able to categorize these models, the depth of their understanding regarding the schematic nature of these models may vary. Further analysis is needed to assess whether students truly grasp the concept of models as abstractions or if they recognize them merely as physical or visual representations. This distinction is crucial for ensuring that students not only identify models but also comprehend their role in representing and simplifying complex systems.

In contrast, the study revealed that models representing processes, mathematical statements or equations, and production schedules were not consistently recognized as models by the students. This observation is primarily based on the absence of these types of models in the students' responses when asked to identify examples of technological models. For instance, models such as flowcharts, production schedules, equations used to represent engineering principles, and symbolic diagrams were notably missing from their responses. One student remarked during an interview, *I thought a model was something physical, like a diagram or a small machine. I didn't realize equations could be models.* Another said, *I know about formulas in math, but I never thought of them as models, just calculations*. This omission suggests a gap in students' recognition of these types of models as valid representations within engineering contexts. Examples of such abstract models can be found in equations representing physical laws, such as Newton's general gravitational force formula in physics or the reaction equation of decomposing water into its components in chemistry, and in production schedules that optimize manufacturing processes.

These observations were further substantiated by two additional qualitative data sources, namely the semi-structured interviews conducted with the 72 essay writers and the open-ended explanation questions embedded in the questionnaire. These data were therefore not collected separately from the procedures already described but constitute the interview and open-response components of those same procedures. Together, these sources revealed that students often struggled to articulate how abstract models like equations, process diagrams, or production schedules fit into their understanding of technological models. For example, when presented with an exploded view or a symbolic equation during the interviews, students frequently failed to classify these as models, indicating a limited recognition of their role in representing engineering concepts. One interviewee stated, *I never thought of a production schedule as a model, it's more like a plan*. On exploded views, one student explained, *Exploded views show how things fit together, but I didn't think of it as a model*. Interestingly, number sequences, graphs, and simulations were occasionally recognized as models; as one student put it, *Graphics and simulations can be models, I think*.

This evidence points to a broader issue: while students may recognize and understand visual or physical models such as scale models or 3D drawings

(*Models are like smaller versions of real things*; *Drawings are models because they show how things look or work*), they may not fully appreciate or identify the importance of models that abstract or symbolize complex processes or mathematical relationships (*Equations are more like calculations, not models*; *I never thought of processes as models, just steps*). Kirchhoff circuits formed a clear exception among the more schematic representations (*I learned about these in physics class, they are definitely models*). Addressing this gap in recognition is crucial for ensuring that students develop a comprehensive understanding of all types of models used in engineering. Table 3 summarizes the extent to which the different model types were recognized by students in the qualitative data.

Table 3

Student Model Type Recognition

Model Type	Recognition	Sample Student Quotes
Real Products	Yes	*I see real products as models we can analyze.*
Scale Models	Yes	*Models are like smaller versions of real things.*
2D and 3D Drawings	Yes	*Drawings are models because they show how things look or work.*
Kirchhoff Circuits	Yes	*I learned about these in physics class, they are definitely models.*
Exploded Views	Sometimes	*Exploded views show how things fit together, but I didn't think of it as a model.*
Equations	No	*Equations are more like calculations, not models.*
Production Schedules	No	*I don't see a production schedule as a model, it's more of a plan.*
Processes	No	*I never thought of processes as models, just steps.*
Graphics and Simulations	Sometimes	*Graphics and simulations can be models, I think.*

Note. In the questionnaire, real products were generally not classified as technological models (Table 4); this divergence between the two data sources is addressed in Triangulation Section.

Quantitative Analysis and Results

Participants and Analytical Procedure

The questionnaire was completed by 338 students (155 girls and 183 boys), 65 of whom had also participated in the qualitative component. In all language groups (Table 1), the questionnaire was written in English, as the students had at least C1 proficiency in that language. Furthermore, the use of pictures helped prevent validity issues related to language differences (Reeves & Hedberg, 2003).

Although the questionnaire was administered electronically in English and students were expected to have at least C1 proficiency, linguistic and cultural differences may still have influenced interpretation. To mitigate potential misunderstandings, visual representations accompanied each item, and qualitative responses were analyzed with attention to contextual meaning rather than literal phrasing. Nevertheless, subtle differences in how students from different language backgrounds interpreted terms such as model cannot be entirely excluded. This represents a limitation of the study and should be considered when interpreting cross-group comparisons.

Upon data collection, rigorous analysis procedures were employed using the statistical software SPSS. Descriptive statistics, including measures of central tendency and variability, were computed to summarize the dataset (Field, 2013). This allowed for a comprehensive overview of students' responses to the questionnaire items and their demographic profiles. Furthermore, inferential statistical techniques (analysis of variance and independent-samples *t*-tests) were applied to examine whether students' conceptions of technological models differed according to background characteristics such as language group, gender, or the presence of STEM subjects in their curriculum (Tabachnick & Fidell, 2019).

In terms of research ethics, all participants were informed about the purpose of the study, and their participation was entirely voluntary. Consent was obtained prior to data collection, and the confidentiality of the students' responses was ensured throughout the process. The use of anonymous electronic surveys further safeguarded the privacy of participants, and no personal identifying information was collected.

Dimensions of Students' Concepts of Technological Models

To analyze the students' responses to the questionnaire, we conducted an exploratory factor analysis on the quantitative data. This analysis aimed to identify underlying dimensions within student responses and to verify the presence of specific categories within the larger sample. Factors were retained based on eigenvalues greater than 1 and inspection of the scree plot. Items with factor loadings above 0.40 were considered meaningful contributors to a factor, while cross-loading items were examined for conceptual coherence before

retention or exclusion. Items were included in a factor when they demonstrated a substantial loading on that factor and conceptual coherence with the emerging construct; items with low loadings or cross-loadings were excluded from scale construction to maintain internal consistency and interpretability.

To construct scale scores from these factors, we selected items that were strongly associated with each factor, using the mean of these items. Items that scored lower on a factor were excluded until excluding them resulted in a significant decrease in Cronbach's Alpha. Cronbach's Alpha was used to evaluate the reliability of each scale, with a threshold of 0.65 considered acceptable for reliability (Nunnally & Bernstein, 1994). Statistical significance was determined using an alpha level of .05. Differences in categorical responses were analyzed using chi-square tests, and for comparisons involving factor scores, mean differences were evaluated and statistical significance was established when $p < .05$. Effect sizes were examined where appropriate to assess the practical relevance of statistically significant findings.

The results of the factor analysis are presented in Table 4. Ten scales were found with at least two items in the questionnaire. All scales had a reliability score above 0.68, indicating acceptable internal consistency for exploratory research, and almost three quarters of the variance was accounted for in the scales that emerged. Each scale represents a distinct concept or category of technological models derived from the data. The Cronbach's Alpha values presented in the second column of Table 4 indicate that all scales meet the reliability criterion when the 0.65 threshold is applied. This suggests that the identified scales provide a consistent measure of the students' perceptions of technological models.

Table 4

Categories of concepts of models in students' questionnaire with mean scores per scale and the corresponding standard deviation

Scales	α	*N*	% σ^2	Cumulative %	*M*	SD
Real products	0.897	4	12.439	12.439	0.11	0.05
Exploded views	0.928	2	10.209	22.648	0.20	0.07
2D drawings	0.879	4	9.672	32.320	0.62	0.11
Scale models	0.845	3	7.528	39.848	0.82	0.06
Equations	0.741	3	6.673	46.521	0.24	0.14
Kirchhoff Circuits	0.925	2	6.257	52.778	0.70	0.19
Production schedules	0.887	2	5.991	58.769	0.35	0.04
Processes	0.682	2	5.867	64.636	0.41	0.06
3D drawings	0.712	2	4.852	69.488	0.75	0.13
Graphics	0.766	3	3.507	72.996	0.59	0.12

To determine whether the scales made conceptual sense, the resulting item groupings were interpreted in light of the qualitative findings from the essay and interview data as well as existing literature on technological models; this comparison is presented in the triangulation section. For example, the following four images came together in the *real products* scale: a picture of a car, a child's dining chair, a picture of a house, and a motorbike. In this context, *real products* refer to tangible, concrete objects that students encounter in their daily lives, such as cars, planes, and household appliances. Although these items can technologically be considered models of design and engineering processes, students perceive them as finished, actual products rather than abstract representations or conceptual models. For the scale *exploded views*, the images of the exploded view of an alternator and an exploded view of a mobile phone came together.

Students' Judgements of the Model Categories

From Table 4, we can deduce that students generally speaking do not see real products as technological models. These responses indicate that students clearly distinguished between representations of objects and the objects themselves. Many students also indicated that *end products cannot be models* as an explanation for their choice in the survey. For exploded view items, the students also indicated that they did not see it as a technological model, but they did not give an unambiguous explanation. Students came up with various explanations; the explanation *Exploded view cannot be a model, because it is a finished product that has been taken apart* was given by a quarter of the students.

One of the most common arguments provided by the students was that a list of components is not considered a model. This was indicated by 38% of the students, the highest percentage for any scale, without further explanation. This lack of elaboration suggests that students found it difficult to articulate why they did not see a list of components as a model. A plausible interpretation is that students tend to associate models with visual or schematic representations that directly relate to the final product, whereas a list of components might be viewed more as a reference or inventory, rather than something that demonstrates the function or purpose of the end product. They seem to expect a model to have a visual or functional connection to a tangible outcome.

In contrast, students did view 2-D drawings as good examples of models, primarily because these were seen as accurate representations of what the final product would look like. This suggests that students primarily understand models as something that visually reflects the form or structure of an object. The notion of a model as a schematic or abstract representation of reality, for them, seems to apply mainly when the model closely resembles the actual object in a visual sense.

However, formulas were not seen as appropriate examples of technological models. According to the students, formulas did not allow them to *directly see the function of the end product*. This reflects a broader difficulty students face in connecting abstract mathematical representations to real-world objects or outcomes. For these students, models need to be something concrete and immediately recognizable as related to a physical or functional product. They struggle to conceptualize formulas as models because they do not offer a direct, visual pathway to understanding what the final product might look like or how it might function.

Another key finding was that many students believed a model should always serve as a preliminary stage in the development of a final product. This belief is reflected in statements such as, *It does not show what it is intended for and does not give an image of a final product*. This suggests that students primarily see models as tools that guide the production process and not as independent representations of systems or phenomena. They seem to feel that a

model must provide clear insights into the practical outcomes of a project, rather than simply representing the relationships or processes at play.

On the other hand, Kirchhoff circuits were considered by students to be good examples of models because they clearly illustrated how the current flows and where the potential differences occurred. A significant proportion of the students noted that *Kirchhoff circuits are models because it is a sketch with all the parts on it: the battery is known, the direction of the current is known, the voltage is known, and even the devices in the circuit are known. A sketch can be a model*. This response indicates that students regard schematic representations, where the relationships between components are clearly visible, as models. The ability to visualize the flow of current and the distribution of voltage helps students perceive the Kirchhoff circuit as a valuable model for predicting and understanding the behavior of the system.

Production schedules and processes, however, were not seen as suitable examples of technological models. Students reported that these did not provide much insight into *predictions about an end product or end result*. This again reinforces the idea that students place high value on models that offer a direct visual or functional connection to a final product. They seem to feel that models should offer predictive power about how something will function or appear in its final form, and production processes or schedules do not meet this expectation.

Scale models and 3D drawings were widely viewed by students as excellent examples of technological models because they were *very accurate representations of reality* and one could *clearly see the functions of the end product*. This highlights the students' focus on the visual fidelity of a model as a key determinant of its value. Models that closely resemble the actual product in terms of form and function were seen as the most useful and accurate representations.

Graphs were also regarded as good examples of technological models, as they allowed students to *understand the effects of different factors on the quantity under investigation*. This indicates that while students place significant emphasis on visual representation, they are also capable of appreciating graphical models that help them conceptualize relationships between variables, especially in quantitative terms. Graphs, while abstract in nature, were nonetheless valued for their ability to visually demonstrate how changes in one factor could influence another.

These findings suggest that students' conceptions of technological models are heavily influenced by the models' visual and functional resemblance to the final product. They appear to struggle with more abstract forms of representation, such as formulas or production processes, which do not provide an immediate or tangible connection to the end result. For students, a model is most effective when it not only represents but also visually communicates the key features and functions of the product or system it is modelling.

Differences Between Subgroups

The number of students per language group allowed us to verify whether a language group as a background variable has a significant influence on students' perception of technological models. We hypothesize that language and cultural differences may impact students' understanding and interpretation of technological concepts. For example, students from different language backgrounds may have varying levels of exposure to technology-related terminology or different educational experiences that shape their conceptualizations of technological models. Additionally, cultural factors such as attitudes towards technology or problem-solving approaches may influence how students perceive and interact with technological models. Previous studies on engineering attitudes and perceptions have indicated that country of origin was a significant background variable that yielded differences (Köycü & de Vries, 2016). Given such findings, it is plausible to expect that similar cultural and contextual factors, reflected in language groups, could influence students' perceptions of technological models. Although there are several groups represented by only a few participants, such as the Bulgarian, Estonian, Latvian, and Lithuanian groups, there are ample groups of adequate size to ensure a robust analysis.

We conducted an ANOVA test to determine whether the language section in which a student is situated influences their conceptions of models. If the significance level (*p*-value) is below 0.05, this would indicate a statistically significant difference between groups based on language section. However, as shown in Table 5, none of the ten scales showed a statistically significant difference; the language section appears to have no influence on any of the scales. The table is included to provide transparency and to document the absence of language-based effects in the dataset.

Table 5

ANOVA Results: Language Section (No Statistically Significant Differences)

Scales	Sig. (*p*-value)
Final products	> 0.05
Exploded view	> 0.05
2D drawings	> 0.05
Scale models	> 0.05
Equations	> 0.05
Kirchhoff Circuits	> 0.05
Production schedules	> 0.05
Processes	> 0.05
3D drawings	> 0.05
Graphics	> 0.05

Following the conduct of the ANOVA, we performed an independent samples 2-tailed *t*-test to investigate whether gender influences students' conceptions, as shown in Table 6. The two-tailed *p*-values for all scales were greater than 0.05, indicating there were no statistically significant differences based on gender across any of the scales. From these analyses, it is evident that neither the language section nor gender yielded statistically significant differences in the conceptions of technological models held by students.

Table 6

Independent Samples Test for Gender

Scales	Sig. (2-tailed) *p*-value
Final products	0.991
Exploded view	0.210
2D drawings	0.748
Scale models	0.482
Equations	0.841
Kirchhoff Circuits	0.441
Production schedules	0.236
Processes	0.897
3D drawings	0.817
Graphics	0.918

With an independent samples *t*-test we investigated whether the background variable of following a STEM course has an influence on the factors found (Table 7). If the significance is lower than 0.05 for a *t*-test, this indicated there was no statistically significant difference in student choices based on a given background variable.

Table 7

Independent Samples Test Following a STEM Course

Scales	Sig. (2-tailed) *p*-value
Final products	.310
Exploded view	.045
2D drawings	.025
Scale models	< .001
Equations	.945
Kirchhoff Circuits	.028
Production schedules	.002
Processes	.675
3D drawings	.003
Graphics	< .001

Results of independent samples *t*-tests revealed statistically significant differences on seven of the ten scales based on students' prior engagement in a STEM subject. The students who took a STEM subject more often called the exploded view an example of a technological model compared to students who do not take a STEM subject. Apparently, engagement in a STEM subject leads to a better image of models in relation to the exploded view scale. With regard to the 2D drawings scale, there was again a statistically significant difference, in that students having previously engaged in a STEM subject saw this scale more clearly as a model than students with no prior engagement in a STEM subject. Scale models were much more often seen as no technological models by students having no prior engagement in a STEM subject than by the other group of students. We can say that for these three scales, where engagement in a STEM subject had an influence on the students' perception, this influence was positive.

However, the answers of the students who did not engage in a STEM subject were better for the Kirchhoff circuits and Production schedules scales than the students with a subject. Apparently, engagement in the STEM subject as it is currently taught gives a misconception with regard to the model function of the circuits and schedules. Because the present design is not causal, this reverse pattern cannot be explained with certainty; one tentative possibility is that the more theoretical treatment of circuits and schedules in STEM subjects draws attention away from their schematic model function, but this would need to be tested directly in future research.

For the scale '3D drawings', the STEM subject students were more often correct and saw the 3D drawings as a technological model. Graphs were also more often seen as a technological model by students with a STEM subject. Also, for these scales, the school subject appears to have a positive influence with regard to the model concept. A likely reason why STEM students performed better on the *3D drawings* and *Graphs* scales could be that these types of models are more directly integrated into STEM curricula. STEM subjects often emphasize spatial reasoning and visual representation, which are key components in understanding 3D models and graphs. In many STEM courses, students regularly encounter 3D models in fields like engineering, physics, and architecture, where these models are used to visualize complex structures and systems. Similarly, graphs are fundamental tools in subjects like mathematics and science for analyzing data and understanding relationships between variables. Therefore, the better performance of STEM students on these scales can be attributed to the fact that these types of models are more explicitly taught and used as learning tools in STEM education, reinforcing their understanding of these models as technological representations. This suggests that the STEM curriculum is effective in conveying the model function of 3D drawings and graphs.

Triangulation of the Qualitative and Quantitative Findings

The study followed an exploratory sequential logic in which the qualitative strand informed the construction of the quantitative instrument, after which the two strands were compared. The qualitative themes derived from the essay analysis were not imposed a priori on the factor analysis but were compared retrospectively with the quantitative factors. This allowed for analytical triangulation, examining whether patterns emerging from students' open-ended descriptions were reflected in their categorical questionnaire responses. In this comparison, attention was paid to whether the findings of the two strands converged, complemented one another, or diverged. Where alignment occurred, this strengthened construct validity; where discrepancies appeared, these were interpreted as indications of conceptual ambiguity rather than forced convergence.

The factors identified through the factor analysis align closely with the categories derived from the students' essays. This consistency is evident in several ways:

1. Category Alignment: The factors revealed by the factor analysis correspond to the categories observed in the essay analysis. For example, the factor related to *Schematic Representation* includes items such as maps and 2D models, which were also frequently mentioned in students' essays under the Schematic Representation Concept. This alignment confirms that the factor accurately reflects the conceptualization of schematic models.
2. High Correlation with Clear Interpretations: The items that exhibited the strongest correlations with each factor were those that provided clear and unambiguous representations of the factor's concept. For instance, the items correlating strongly with the *Scale Model* factor included mini cars and model planes, both of which were prominently featured in the essays as examples of scale models. This strong correlation underscores the factor's validity in representing scale models as described by students.
3. Examples of Consistency: (a) Schematic Representation Concept: Essays frequently cited maps and floor plans as examples of schematic representations, and factor analysis identified a factor where these items had high loadings, reinforcing the idea that students consistently view these models as schematic. (b) Number Sequences and Graphs Concept: Students' essays often included references to graphs and equations as tools for representing numerical data, and the factor analysis similarly identified a factor with strong correlations to these items, demonstrating consistency between essay content and factor identification. (c) Functional Representation Concept: Functional models such as source codes and production processes were mentioned in essays and also appeared as high-loading items in the corresponding factor, indicating that students' descriptions of functional models are accurately captured by this factor.

4. Validation through Item Correlation: The validity of the factors is further supported by the fact that the items with the highest correlations were those that allowed for a straightforward and accurate interpretation of the factors. For example, items like Kirchhoff circuits and physics equations, which were strongly associated with the 'Functional Representation' factor, clearly fit the concept of functional models as defined by the essays.

The strong alignment between the factor analysis results and the conceptual categories identified in the essay analysis supports the validity of the factors. This consistency indicates that the factors derived from the quantitative data reflect the conceptual understandings described by students in their essays. An important argument for validity is that the items that correlated most strongly with a factor in all cases allowed for a clear and unambiguous interpretation of the factor. The analysis thus revealed notable similarities between the content of students' essays and their responses to the digital questionnaire.
One notable divergence between the two strands concerned real products. In the essays and interviews, real products were mentioned among students' examples of models, whereas in the questionnaire students generally did not classify real products as technological models (Table 4). In line with the analytical approach described above, this divergence is interpreted as an indication of conceptual ambiguity in students' understanding of the boundary between a model and the object it represents, rather than as a contradiction between the two data sources.

Conclusions

The conclusions of this study are organized in relation to the main research goal (identifying the conceptions upper secondary students hold regarding technological models) and the secondary goal (exploring which factors may impart an influence on these conceptions).

Students' Conceptions of Technological Models

With regard to the main research goal, the findings show that upper secondary students possess a basic understanding of technological models, yet their conceptions remain strongly tied to visual resemblance and proximity to a final product. Students' ideas about the nature of a technological model, as found in this study, suggest that according to students a technological model should be a complex entity, where the representation of reality seems to be a prerequisite. This view was reflected in almost all of the students' essays, which included representations such as 2D drawings, scale models, and 3D diagrams. However, many students did not consider formulas, production schedules, or processes to be technological models, likely because they do not directly resemble the final product. This suggests that students' conceptions only partially align with the

definition of technological models proposed, particularly with respect to their functional, predictive, and design-oriented roles. From a conceptual perspective, the distinction students made between representations and the objects themselves is appropriate, as physical objects do not constitute models but may serve as referents for modelling activities.

Interestingly, there was no significant division in this study between students' views on technological models as schematic representations, scale models, number sequences, or graphs. What was clear from both the essays and the interview data is that students consistently viewed technological models as something directly related to the final product or outcome. The triangulation of the two strands confirmed this picture, showing notable similarities between the content of students' essays and their questionnaire responses. In contrast to previous studies among lower secondary school students, a distinct concept of a technological model was thus found among the upper secondary participants in this study.

Factors Influencing Students' Conceptions

With regard to the second research goal, no statistically significant differences were observed within the limits of this dataset with regard to language section (Table 5) or gender (Table 6). The absence of gender differences is particularly noteworthy because previous research at the lower secondary level has identified gender differences, but no such disparity was found here (Nia & de Vries, 2017).

Engagement in a STEM school subject, in contrast, was associated with statistically significant differences on seven of the ten scales (Table 7). For the exploded views, 2D drawings, scale models, 3D drawings, and graphics scales, students with a STEM subject responded more in line with the technological model concept, whereas for the Kirchhoff circuits and production schedules scales, students without a STEM subject gave answers that were more in line with that concept. Relatedly, for the half of the students for whom education in aspects of engineering is not part of their curriculum, representativeness was a greater requirement (84% of the essays) than for students who have a subject in which aspects of engineering are taught (48% of the essays). Although these differences are statistically significant, the magnitude of the observed differences should be interpreted with caution (Chittleborough et al., 2005; Nia & de Vries, 2017). In summary, the findings tentatively suggest that exposure to STEM subjects may be associated with differences in how students conceptualize technological models; however, no causal conclusions can be drawn from the present study.

Discussion

The discussion is organized around the implications of the findings. The findings are first interpreted in relation to prior research, after which

implications for curriculum design and for teacher education, as well as limitations and directions for future research, are discussed in separate sub-sections.

Interpretation in Relation to Prior Research

The strong association between technological models and visual resemblance to a final product aligns with earlier findings on students' conceptions of engineering (Köycü & de Vries, 2016) and parallels observations in science education research, where students often associate models with accurate visual representations (Gilbert et al., 2000; France, Compton, & Gilbert, 2011). Consistent with previous research on models in technology and engineering education (Nia & de Vries, 2017), students in this study tended to associate technological models with representations that directly communicate the characteristics of a final product, rather than with abstract or functional representations. This is a notable misconception that has been identified in other research as well (Gilbert et al., 2000), and it is consistent with Haglund and Strömdahl's (2012) findings, which highlighted students' preference for visual or tangible models over abstract representations like formulas.

Our results further indicate that secondary school students possess a more developed understanding of technological models compared to primary school students. This progression is expected, given the age and educational differences, and suggests that secondary education provides a more solid foundation for students to engage with more complex technological activities. This developmental trajectory aligns with earlier research on the evolution of students' conceptualizations of models (Chittleborough et al., 2005) and supports the notion that educational progression contributes to a deeper understanding of both scientific and technological models. Previous studies, such as the one by Gilbert (1998), indicated that primary and secondary school students often perceive models in science as needing to be accurate representations of reality. Although these studies did not specifically address technological models, our findings suggest that a similar perception may extend to students' understanding of technological models as well.

This pattern may be understood in relation to students' prior learning experiences. In many school subjects, models are introduced primarily as visual or tangible representations (e.g., molecular models in chemistry or anatomical models in biology), which may reinforce the idea that resemblance to a final product is a defining characteristic of a model. Abstract or symbolic representations, such as equations, process diagrams, or production schedules, are often taught as computational or procedural tools rather than as models in their own right. As a result, students may not develop a broader understanding of models as functional representations that support analysis, prediction, and design decision-making. An interesting question, which begs for further investigation, is why students think that a technological model must directly

reflect the final product or outcome and cannot be a diagram, a process, or a formula.

Implications for Curriculum Design

From a pedagogical perspective, the findings suggest that technology and engineering education should explicitly address the multiple forms and purposes of models. Educational materials that provide balanced attention to all aspects of technological models may help improve students' overall perception and address the misconceptions found between students with and without engagement in STEM subjects. If future research confirms that exposure to STEM subjects is associated with broader understandings of technological models, curricula might consider more explicit integration of different model types (physical, schematic, symbolic, and procedural) within design-oriented activities. Instructional approaches could include comparing physical, schematic, symbolic, and procedural models of the same system, as well as making the role of models in design processes more explicit. Such strategies may help students move beyond a purely product-oriented view of models and develop a more integrated conceptual understanding. Our results suggest that future studies should also explore ways to teach students that technological models encompass a wider variety of representations, beyond just visual likenesses to reality. This highlights the importance of explicitly teaching the representational and functional nature of models in technological contexts.

Implications for Teacher Education

Beyond curriculum considerations, these findings underscore the importance of strengthening teacher education in technology and engineering. If teachers themselves predominantly conceptualize models as visual representations rather than as functional design tools, classroom practice may unintentionally reinforce a narrow understanding of modelling. Teacher preparation programs should therefore explicitly address the epistemological status of technological models and provide opportunities for prospective teachers to engage in modelling as an iterative and design-oriented practice. Professional development initiatives might include explicit strategies for discussing with students why equations, simulations, and process models also function as technological models. Making these distinctions explicit in classroom practice may help reduce the narrow, product-oriented view identified in this study and may help bridge the gap between students' representational conceptions and the broader functional roles of technological models.

Limitations and Future Research

Several limitations of the present study should be acknowledged. The schools were selected through convenience sampling; although the participants represented 13 language backgrounds (Table 1), they were drawn from only two

international schools in a single city, so the linguistic diversity of the sample should not be read as geographic or institutional representativeness, and the findings should be interpreted as context-bound rather than universally generalizable. The binary (True/False) format of the questionnaire limited the degree to which nuanced understanding or uncertainty could be captured, and subtle differences in how students from different language backgrounds interpreted terms such as model cannot be entirely excluded. Furthermore, perhaps the use of certain tools, such as molecular models in chemistry or anatomical models in biology, where representativeness is often part of the model, has influenced what students expect from a technological model; the present design cannot separate such prior experiences from the influence of the current curriculum.

These findings provide a basis for further investigation. Future research could explore these aspects in greater depth to better understand the nuances of students' perceptions and the potential impact of gender and educational background on their understanding of technological models. Incorporating Likert-scale items or open-ended follow-up questions could allow for more differentiated expressions of understanding, and longitudinal designs could examine how students' conceptions of technological models develop once these concepts are explicitly introduced in the engineering curriculum.

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