PATT43: The 43rd International Pupils' Attitudes Towards Technology Research Conference
Hosted by the Swedish National Centre for School Technology Education (Cetis) and Technology and Science Education Research (TekNaD), Linköping University, Norrköping, Sweden, June 15th to June 18th, 2026

# Reframing Engineering Literacy: A Comparative Synthesis of International Competence Frameworks

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***Abstract***

Based on a systematic literature review of international competence frameworks that aim to integrate engineering-related practices into general school education in STE(A)M contexts, this paper examines how central ways of working and thinking in engineering can be located and operationalised within school-based technology education. Using a comparative synthesis, the analysis identifies recurring dimensions across a heterogeneous body of models and classifies the identified approaches into three overarching framework types: (1) *design- and problem-solving-oriented frameworks,* (2) *competency-oriented frameworks,* and (3) *curricular or domain-specific frameworks*. Across these types, a patterned asymmetry becomes visible: procedural elements (engineering design cycles) and cognitive elements (engineering habits of mind) are typically described in teachable terms, whereas the normative dimension (explicit evaluation and responsibility in relation to societal, ecological, and economic consequences) remains underdeveloped and is often treated merely as contextual "constraints". Rather than proposing yet another national model, the paper develops a synthesis that consolidates distinctive features of existing approaches, discusses their compatibility with the Common Reference Framework for Technology (GeRRT), and argues for a hybrid perspective that links iterative process structures with transferable habits of mind while making normative evaluation an explicit educational outcome.

*Key Words: Engineering Literacy, Competence Frameworks, STEAM Education.*

## 1 INTRODUCTION

Beyond being just a professional field, engineering is establishing itself as an important approach of modern education; and while it is taking root at varying speeds across the globe, many nations are already leading the way in integrating it into their curricula (e.g., Lai & Cheng, 2023; Purzer et al., 2021). Within the context of STE(A)M, there is a growing emphasis that learners should not only understand scientific concepts or mathematical models but also become familiar with the specific ways of thinking and approaching problems, or: "prototypical engineering practices", used to design, test, improve, and integrate technical solutions into societal contexts. Under terms such as *engineering literacy* or *engineering practices*, a perspective emerges that views

technology education not merely as the transmission of knowledge about artefacts and the use of tools, but as a learning space for tackling complex problems, balancing competing requirements, and developing solutions in a structured manner (Srikoon et al., 2024; Wan & Lee, 2023).

At the same time, educational research reveals a certain lack of conceptual clarity. While international competency frameworks and models exist (e.g., Purzer et al., 2021; Srikoon et al., 2024), their terminologies, priorities, and underlying dimensions vary considerably. Some studies place *User-Centred Design* at the forefront, while others focus on the iterative *Design-Build-Test* cycle. Still others view *Engineering Thinking* as the essential hallmark of engineering theory and practice that needs to be translated into the school environment. Furthermore, problem-oriented pedagogical approaches, such as *Problem-Based Learning*, are frequently used as a bridge to make engineering practices accessible within school settings (Halawa et al., 2024). This diversity is productive yet complicates the question of how central dimensions of engineering can be systematically located and designed within technology education, especially when ensuring compatibility with German-speaking reference frameworks.

Against this background, the present article pursues a clear objective: based on a systematic literature review (SLR) of international framework models, it investigates which recurring dimensions of prototypical engineering ways thinking and approaches are described in key studies. It examines how these dimensions relate to one another and identifies unique approaches that may not be found across all models. Specifically, we distinguish between three levels:

(i) *procedural* (Engineering Design),
(ii) *cognitive* (Habits of Mind),
(iii) and *normative* (Evaluation and Responsibility).

The goal is not to draft another isolated national model, but to propose a comparative synthesis that international approaches, highlights distinct characteristics, and assesses their transferability to German-speaking educational contexts. In doing so, we demonstrate how engineering practices already present in technology education can be systematized and structured for adaptation across various curricular contexts. Ultimately, this contribution serves as an impetus to firmly ground *Engineering Literacy* in curricular and conceptual debates and to support the further development of technology education in coherent alignment with international discourse.

## 2 METHODOLOGY

This study employed a systematic literature review based on the methodology of Nordhausen and Hirt (2022). To maximize the retrieval of relevant literature, the investigation followed a sensitive search strategy. The operationalization of the research question involved thematic clustering instead of traditional schemas like PICO or SPIDER. Methodological and pragmatic considerations led to the selection of three key databases: EBSCO, SCOPUS and Web of Science. After identifying the necessary terms and descriptors, the research team constructed and piloted

an initial search string. While the primary search was executed during the summer of 2025, the data collection includes all records identified up to the cut-off date of April 15, 2025.

The search terms were organized into four thematic clusters to refine the focus of the results while accounting for terminological variations within the international discourse. In each cluster, synonyms and related terms (e.g., “competency framework” vs. “educational standards”) were linked using the “OR” operator to capture diverse nomenclature. Subsequently, these clusters were combined using the “AND” operator. This ensured that the final selection only included publications that simultaneously addressed a school-based target group, provided a framework-like description of competencies, related to engineering or technology education, and maintained a specific focus on competency or literacy. Table 1 provides a summary of the thematic clusters and search strings.

**Table 1**

*Search terms and thematic clustering*

| Thematic Cluster | Search Terms | Explanation |
|---|---|---|
| Target Group | ("K-12" OR "school students" OR "students" OR "learners" OR "pre-college" OR "primary education" OR "secondary education" OR "elementary school" OR "high school") | Definition of the educational level and delimitation of the search to the school sector (K-12 or primary/secondary level and equivalent terms); exclusion of higher education or vocational training |
| Content | ("competency framework" OR "competence framework" OR "skills framework" OR "competency model" OR "framework of competencies" OR "educational standards" OR "learning outcomes" OR "curriculum framework") | Types of text or artifacts being searched for |
| Framework / Context | ("engineering" OR "engineering education" OR "engineering skills" OR "technical education" OR "STEM" OR "technology education" OR "design-based learning" OR "maker education") | Definition of the subject area and related pedagogical approaches |
| Context / Domain | ("competence" OR "competency" OR "skills" OR "literacy" OR "capabilities" OR "problem-solving" OR "design thinking" OR "21st century skills") | Specification focusing on contributions to competence, ability, or literacy concepts |

A total of 2,132 articles were identified across the Web of Science, EBSCO and Scopus databases. The records, including their abstracts, were subsequently uploaded to Rayyan, a web-based application designed for conducting systematic literature reviews. Following the removal of 496

duplicates and 23 non-English or non-German records, an additional 1,524 datasets were excluded after title and abstract screening. This cleaning process resulted in 89 records remaining for full-text analysis. To ensure the reliability and credibility of the selection, the full-text screening was conducted using a double-blind procedure (Covidence, 2024). The inclusion and exclusion criteria were aligned with the research question and the previously developed thematic clusters. Both the double-blind approach and the specific criteria served to maintain methodological rigor and ensure a transparent documentation of the selection process (Covidence, 2024; Higgins et al., 2024).

The final corpus of selected frameworks served as the basis for the comparative synthesis. For the analysis, we used the paper's conceptual distinction between procedural (Engineering Design), cognitive (Habits of Mind), and normative (Evaluation and Responsibility) dimensions as a cross-cutting analytical lens. For each framework, we examined (a) whether and how design processes are operationalized as learnable classroom practices (procedural), (b) which transferable ways of thinking are foregrounded (cognitive), and (c) whether evaluative judgement and responsibility are articulated as explicit competencies with concrete decision criteria (normative), rather than being mentioned only as contextual "constraints". This dimension-based reading allowed us to align diverse terminologies and structures and, importantly, to identify not only what is present across frameworks but also what tends to remain implicit or underdeveloped.

## 3 RESULTS

Following the full-text screening, data extraction was conducted using a standardized protocol. Of the 89 records assessed, 61 were excluded because they did not meet the inclusion criteria. Studies were excluded when they did not present a framework, when they addressed non-school educational settings, or when they were situated in subject domains other than technology education (e.g., biology education). The review specifically focused on approaches that seek to integrate engineering competencies into technology education through framework-based approaches. In addition, a considerable number of records proved difficult to classify during the initial screening because they addressed school engineering but specified content or activities, not competencies. This highlights an underlying challenge in the literature, namely the lack of consistent terminology and clear distinctions between competence-oriented frameworks and other types of educational frameworks. For the remaining 28 cases in which initial disagreement occurred between the researchers, a structured consensus procedure was employed, involving re-analysis and joint alignment with the exclusion criteria. Ultimately, 7 articles met all inclusion criteria and were selected for final analysis. The core data extracted included bibliographic information (author, year, title), the thematic domains, and central research findings.

Based on this, the engineering-related frameworks identified in the literature are categorized by their thematic domains within the context of general technology education. These domains are systematically detailed in Table 2 (here exemplified by the Purzer et al. Framework due to space constraints), which specifies the (1) author, (2) year of publication, (3) specific domains, and (4) a brief contextualization for the school setting.

**Table 2**

*Identified domains, exemplified through the 'Honeycomb of Engineering' framework (Purzer et al., 2021)*

| Author | Pub | Domains | Explanation |
|---|---|---|---|
| Purzer et al. | 2021 | User-Centred Design | Students work with real or simulated users or contexts, identify their needs, and develop solutions that are guided by those needs. |
| | | Design-Build-Test | Students are given clear criteria, generate different solutions, build prototypes, and test them to demonstrate functionality. |
| | | Engineering Science | Students conduct controlled experiments, deliberately vary one variable, and thereby gain technical knowledge. |
| | | Engineering Optimization | Students analyse existing systems, compare key criteria, and improve their performance using calculations or practical tests. |
| | | Engineering Analysis | Students use data, models, or calculations to draw conclusions about technical systems without having to build a prototype. |
| | | Reverse Engineering | Students examine an existing product, systematically take it apart, document its structure and how it works, and develop ideas for improvements or redesigns. |

## 4 CONCLUSION

### *4.1 Engineering as a Discipline vs. a Practice*

The present analysis reveals that the term “engineering” is too narrow to characterize general educational competencies in a school context, as it predominantly evokes associations with purely academic bodies of knowledge. As noted by the European Commission (2024):

> "Technology and engineering are firmly grounded in applied knowledge, which often presents challenges in school settings due to its highly contextual and specific nature (Feenberg, 2002; Dasgupta, 1996; Pacey, 1999; Skolimowski, 1966). […] Technology and engineering are often regarded as domains focused on preparing students for specific careers, thus making it a vocational subject at the collegiate level where its curriculum is tailored to meet the needs of particular occupational fields (Oaks, Leone & Gunn, 2001)."

A significant conceptual challenge lies in the translation of the term itself: While the English term 'engineering' seamlessly functions as both a noun for the discipline and a verb describing the prototypical ways of acting and thinking, the German equivalent 'Ingenieurwissenschaften' remains linguistically tied to its academic and theoretical roots ('science of engineering'). In German, there is no direct verbal equivalent that captures the dynamic, iterative process of 'doing engineering' in a classroom context.

***Table 3***

*Conceptual Nuances of 'Engineering' in English and German Contexts*

| English Term | German Equivalent | Nuance / Limitation |
|---|---|---|
| Engineering (as a discipline) | Ingenieurwissenschaften | Very academic, implies higher education |
| Engineering (as an activity) | No direct equivalent | Often translated as "Technisches Gestalten" or "Konstruieren," but these lack the professional "engineering" scope |
| Engineering thinking<br>Habits of mind | Ingenieurwissenschaftliche Denkweise(n) | Accurate, but lacks the "hands-on" active component of the verb |
| "doing" Engineering | Ingenieurmäßiges Handeln | The closest pedagogical term, emphasizing the *way* things are done |

This conceptual ambiguity is reflected in the empirical findings of Moriyama et al., who encountered similar difficulties in reaching a consensus on the term 'Engineering' within their framework:

> "However, the concept of the term 'Engineering (2.78) had a mean value of less than 3.00 and a larger SD than the others. Therefore, in the last version the concept of the term 'Engineering' was revised, and the framework was completed." (Moriyama et al. 2024)

To align with the pedagogical objectives of general technology education, and in accordance with the frameworks identified, the term *'engineering-typical'* (*ingenieurtypisch*) is preferred hereafter. This deliberate shift in terminology marks a crucial distinction: while 'engineering' primarily addresses the academic discipline and its theoretical foundations, 'engineering-typical' targets the specific methodological identity and the characteristic ways of thinking and acting inherent to engineering. The adjective 'typical' emphasizes transferable core practices (e.g., iteration, systems thinking, optimization under constraints) that serve as viable problem-solving strategies for non-engineers in a technologized world. Consequently, the transfer from specialized science to general schooling is understood not as a mere reduction of content, but as the extraction of a technological logic of action. This approach transcends mere curricular simplification. Instead, it represents a functional transposition: rather than diluting engineering science, it isolates

the discipline's core cognitive and procedural architecture. By focusing on this technological logic of action, students engage with authentic engineering challenges, such as navigating uncertainty and optimizing under constraints, at an appropriate level of complexity. Consequently, the integrity of the engineering mindset is preserved, shifting the pedagogical focus from static knowledge acquisition to iterative process proficiency.

### *4.2 Categorization of identified Frameworks*

Although the seven frameworks vary considerably in their pedagogical entry points, they can be systematically compared by tracing how each model makes engineering-typical action teachable (procedural), how it frames transferable engineering thinking (cognitive), and how it connects design decisions to evaluative judgement and responsibility (normative). Using this lens, our results not only map common ground across models but also reveal a patterned asymmetry: normative aspects are frequently acknowledged in principle yet rarely operationalized as an independent competency dimension with explicit criteria.

The literature review demonstrates that while the international discourse encompasses a broad range of work on engineering education, only a small subset develops or systematically describes explicit frameworks for the school context (Lai & Cheng, 2023; Moriyama et al., 2023; Srikoon et al., 2024; Wan & Lee, 2023; Halawa et al., 2024; Reynante et al., 2020; Purzer et al., 2021). The identified contributions can be classified into three overarching categories:

(i) Design- and problem-solving-oriented frameworks
(ii) Competency-oriented frameworks
(iii) Curricular or domain-specific frameworks

The works of Lai & Cheng (2023), Wan & Lee (2023), Reynante et al. (2020) and Purzer et al. (2021) fall into the first category. These frameworks typically describe phases such *as problem definition, idea generation, modelling, construction, prototyping, testing, reflection* and *optimization*. They define general technology education as empowering learners to tackle open-ended, authentic problems through *engineering-typical* procedures. Characteristically, they emphasize iterative processes, work with prototypes, and the integration of scientific knowledge into technical solution strategies.

Articles by Srikoon et al. (2024) and Halawa et al. (2024) focus on engineering habits of mind rather than concrete iterative steps. This includes systems thinking, linking cognitive models, a scientific understanding of technology and developing the capacity to participate in technological innovation and societal solutions. Here, general technology education is understood as building a cluster of subject-specific, methodological, social and reflexive competencies that enable learners to understand, evaluate, and actively shape technical phenomena.

Moriyama et al. (2023) fall into the third category. Their NGTE ("New Framework of Technology and Engineering Education") is explicitly developed as a curriculum-standard-like reference for

Japan´s upcoming national curriculum revision. In contrast to generic process or competency models, the paper anchors its framework in the concrete national subject structure of Japanese secondary education while also being designed as a bridge for transdisciplinary STEAM learning across subjects. Regardless of whether these frameworks are process-oriented or competency-centred, they share the goal of making *engineering-typical* patterns tangible for learners. They transform highly contextualized engineering knowledge into structured learning pathways.

### *4.3 Identifying the Normative Gap*

Despite this diversity, the analysis reveals a significant gap: while the procedural dimension (*Engineering Design*) and the cognitive dimension (*Habits of Mind*) are well-developed, the normative dimension (the explicit link to *Evaluation and Responsibility*) remains underexposed. Although the theoretical definition of the engineer as a "cultural profession" places ethical responsibility at its centre, the analysed frameworks often neglect this in favour of technocratic processes. For true 'Engineering Literacy' aimed at societal participation, closing this gap is essential.

*Engineering-typical* actions are often portrayed as methodologically neutral. The fact that every technical solution is embedded in a complex web of social, ecological, and economic interactions is occasionally mentioned as a 'constraint' but is rarely operationalized as an independent, critical competency area for general education. Without this, frameworks risk promoting a functionalist understanding of technology where functionality eclipses appropriateness and consequences.

Across all three categories of frameworks, a consistent pattern emerges when reading the models through the procedural–cognitive–normative lens: while procedural components (e.g., iterative design cycles) and cognitive components (e.g., systems thinking and other habits of mind) are described in comparatively rich and teachable terms, the normative dimension—i.e., the explicit linkage between design decisions, evaluation, and responsibility—remains underexposed. Even when frameworks acknowledge that engineering solutions are embedded in social, ecological, and economic contexts, such considerations are most often framed as external constraints on an otherwise methodologically "neutral" process rather than as a core educational outcome that requires explicit criteria, deliberation, and justification.

This imbalance matters for the very goal many frameworks claim to serve: enabling learners to participate in and shape a technologized world. If evaluation is reduced to functionality and efficiency, learners are left with a functionalist view in which "what works" risks overshadowing "what is appropriate" and "at what cost". Therefore, the normative dimension should be treated not as an optional add-on but as a constitutive component of engineering literacy in school contexts.

The identified normative gap is not an isolated weakness of individual models but a systematic outcome of approaches that privilege either process descriptions or mindset taxonomies without explicitly anchoring evaluative responsibility as a teachable practice. This motivates the

following proposal of a hybrid approach that links procedural structure and cognitive transfer while making normative evaluation visible within engineering-typical action.

### *4.4 The Necessity of a Hybrid Approach*

The analysis clarifies that focusing on a single category is insufficient for general technology education. Instead, we suggest a hybrid approach that inseparably links the process-oriented logic of *Engineering Design* (the *how* of making) with the competency-oriented development of *Habits of Mind* (the *how* of thinking). This hybridization resolves the challenges posed by the "highly contextual nature" of technical knowledge (European Commission, 2024, p. 9). While pure engineering science remains tied to specialized contexts, the combination of iterative processes and transferable mindsets provides a pedagogical scaffolding manageable in everyday school life:

- *Process orientation* establishes the necessary structure for the classroom, providing a "common thread" that guides learners through complex projects
- *Competency orientation* ensures long-term transfer value, transforming specialized technical knowledge into versatile strategies for real-world problem-solving
- *Action-oriented integration* serves as the vital link between *process* and *competency*: it is through the rigorous application of the iterative process that students internalize the transferable mindsets necessary to actively navigate and shape their environment

An *engineering-typical* pedagogy based on this hybrid model presents technology not as a static canon of knowledge, but as a dynamic, methodologically guided form of world-shaping. Thus, school does not serve as a mere precursor to university but as a place where students learn to master the complexity of a technologized world through systemic thinking and iterative problem-solving strategies.

### *4.5 What lessons can Germany draw from this?*

While the Common Reference Framework for Technology (GeRRT)[1] outlines a clear vision for "technological literacy", ranging from elementary use (Level A) to complex development (Level C), the reality of schooling in Germany presents a more nuanced picture: In federal states such as Lower Saxony, technology education is firmly anchored in the core curriculum (KC), yet it often

[1] The Common Reference Framework for Technology (GeRRT) is a German reference framework developed in the VDI (Verein Deutscher Ingenieure) context to describe and differentiate technological competencies across educational settings. Structured into three levels (A: elementary, B: extended, C: complex) and five domains – understanding, using, developing, evaluating, and communicating technology – it provides a conceptual framework for discussing technological literacy. In this article, we use GeRRT as an analytical reference point because it offers a systematic language for examining the extent to which school-based technology education addresses not only the safe use of technology, but also processes of technological development.

aligns with traditional competency areas: *subject knowledge*, *inquiry/acquisition of knowledge*, and *evaluation/assessment (Gerste et al., 2021; N-KM, 2010)*. For example, there is a heavy emphasis on "safe operation" of machinery and the correct use of tools. While this is essential for safety and provides a solid vocational foundation, it falls short of true engineering. What is frequently missing in German classrooms is the iterative process, a defining element of engineering often portrayed in the cycle of d*esign-build-test-redesign,* exemplifying the discipline's approach to problem-solving. In current everyday schooling, the focus is often on achieving a "perfect" final product, rather than embracing failure as a necessary step for gaining insight within the development process.

In comparison to the identified approaches, POD (*Process of Design*), which organizes learning in a much more granular and process-oriented manner, is a more dedicated path that incorporates a *positive failure culture*. Internationally, "failure" is often more actively integrated into the learning process. There, the iterative cycle is not merely a side note but the pedagogical backbone. The same can be said about *Engineering Thinking*: While technology education in Germany often resembles traditional "shop class" under a modern guise, other countries are more consistent in translating engineering mindsets, such as systems thinking and problem solving, into the classroom. However, true procedural competence (engineering-based action), which requires high error tolerance and constant iteration, often remains reserved for university education, a gap that must be closed to provide a comprehensive general education.

## 5 DISCLOSURE

The authors utilized ChatGPT and Google Gemini to assist in translating the manuscript from German to English and to refine the linguistic flow. AI tools were not employed for data analysis, the generation of original research content, or the formulation of the core scientific arguments. All AI-generated suggestions were critically evaluated for accuracy and edited by the authors to ensure the integrity of the scientific argument.

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