On Hidden Shortcomings That Hinder Understanding: Thought-Provoking Observations from a Soft Skills Development Program for Engineering Students

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Abstract. Due to technological advancements, changing expectations of engineers, and shifts in students' attitudes and preparedness, the conditions of engineering education are constantly evolving. Those involved in higher education pedagogy often attribute the learning difficulties observed in engineering subjects exclusively to deficiencies in secondary school education, particularly in mathematics and the natural sciences. This study draws attention to the fact that this is only the easily observable level; behind the comprehension problems, a deeper erosion of knowledge is taking place, which is much harder to recognize, and standard testing methods are not suitable for this. This refers to the fading of experiential knowledge derived from the direct experience and interpretation of the physical world – knowledge that previous generations acquired naturally and unconsciously through childhood play, and later through physical activity and manual labor in their youth. We created a three-layered model to interpret the observations from the soft skills development program implemented at the Faculty of Engineering, University of Debrecen, and to serve as a framework for further research. This is a conceptual framework that distinguishes between the easily identifiable and readily assessable elements of formal school education – the second layer – and the hidden elements of experiential knowledge, which are difficult to detect and manifest indirectly, the foundational layer. Through the results of an experiment conducted with 382 first-year engineering students, we demonstrate that the difficulties in fundamental engineering problem-solving stem primarily not from a lack of defined academic knowledge, but from a lack of thinking related to real-world systems and processes, and a lack of fundamental physical and engineering intuition. In the experiment, first-year engineering students solved special tasks designed for this purpose through teamwork. The analysis is based on the submitted written work and observations of communication during the teamwork.

Keywords: Engineering Education, Experiential Knowledge, Soft Skills, Physical Intuition, Digital Natives, Problem-Solving.

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1 Introduction

The world of engineering education is characterized by continuous transformation, which is influenced today by several mutually reinforcing factors.

Keeping pace with rapid technological advancements requires new content and methods; moreover, changes in the social role of engineers also place new demands on graduates. Changes in young people's attitudes, habits, and prior experiences are altering the conditions under which learning takes place. These changes have been discussed in the engineering education literature for decades [1], [2]. The CDIO (Conceive–Design–Implement–Operate) framework, for example, explicitly argues that engineering education should integrate theoretical and practical knowledge, placing the "learning by doing" philosophy at its core.

It is often noted among engineering educators that the general level of knowledge among incoming students is declining steadily and at a significant rate. The authors generally diagnose gaps in the knowledge acquired in public education and, within this framework, have concluded that students entering higher education have not learned or have forgotten key concepts, relationships, and methods. Accordingly, the responses focus on testing and addressing these gaps in mathematics and science. In [3] the authors pointed out that the quality and structure of prior knowledge fundamentally influence the acquisition of new knowledge, distinguishing between declarative, procedural, and informal knowledge elements. Testing knowledge in mathematics and the natural sciences is relatively straightforward, as the necessary competencies can be clearly defined, and appropriate assessment tools are available.

The primary motivation for our study is that instructors of technical subjects do not understand why engineering students often get stuck on a particular step in problem-solving. Since technical models and calculations are based on mathematical tools, they logically approach the issue from the perspective of computational ability and attribute the difficulties to gaps in formal knowledge.

The authors were guided by their experience with the Soft Skills Development Method (SSDM) [4] – originally developed for advanced engineering courses at the Faculty of Engineering of the University of Debrecen and later applied in introductory mathematics courses [5], in devising a method for investigating the root causes of problems. Experiences gained from applying Brain Maintenance – one of the core elements of the SSDM – among first-year engineering students suggest that the roots of comprehension and problem-solving difficulties lie in areas beyond the scope of knowledge acquired in school [6].

In this study, we present observations indicating that a significant portion of the knowledge possessed by students beginning their engineering studies lacks elements whose absence would have been unimaginable a decade or two ago. The modern lifestyle makes it impossible to directly experience and analyze real-world phenomena, so students do not acquire the realistic thinking and judgment that form the indispensable foundation of engineering work.

Technical science and engineering are conservative fields; expectations are clear and strict. The fundamental content elements of preparation for the responsible role of an engineer do not change, while generations are entering the training program who are

encountering for the first time in their engineering education how to think about a technical system or process.

Since it was natural for the teaching generation to acquire experiential knowledge through lived experiences (play, sports, work), they are not aware of the role of this layer of knowledge; consequently, its absence does not even occur to them.

Consequently, they test and attempt to supplement formal knowledge, which is completely ineffective for some students.

In the research, we employed exploratory observation, in which specific tasks function as diagnostic tools. The thinking processes observed during teamwork and the identification of factors hindering problem-solving are informative. The tasks are designed so that every student is expected to be able to solve them: only very basic learned knowledge is required, with the emphasis on understanding the problem and thinking skills. We drew conclusions about why some students were unable to solve the tasks and what aspects of the world around them they did not understand.

While standard tasks assess whether a student possesses specific knowledge – such as the ability to write down a mechanical relationship or solve an equation using a learned method – the key question in specialized tasks is whether the student can fully understand the problem and develop the appropriate way of thinking. Observations indicate that a lack of knowledge of the fundamental facts of the physical world – which is necessary for engineering problem-solving – remains a problem today. And it is foreseeable that the continued rise of virtual reality in children's lives will further exacerbate the situation. To maintain the effectiveness of engineering education, it is necessary to systematically examine real-world knowledge and apply teaching methods that take into account that "natural knowledge" is different for new generations.

2 Layers of Knowledge, Levels of Learning

2.1 Experiential and Formal (School) Knowledge

The role of free play and physical activity in childhood cognitive development has become a central theme in developmental psychology and pediatric research over the past decade. The official statement of the American Academy of Pediatrics [7] emphasizes that unstructured, physical play is essential for cognitive, social, and motor development: outdoor play develops gross motor skills: balance, coordination, and muscle strength, while playing with objects (building, modeling, drawing) contributes to the development of fine motor skills. In [8] the author argued that free play is the context in which children learn self-regulation, planning, and problem-solving – that is, the primary arena for the development of executive functions. In their longitudinal study, the authors of [9] demonstrated that complex construction play in preschool predicts later mathematical performance in formal education, which is direct evidence that physical object manipulation lays the foundation for abstract thinking.

The relationship between physical activity and executive functions was confirmed in [10]: regular physical activity significantly improved children's inhibitory control and cognitive flexibility, a finding supported by brain imaging studies. In his comprehensive review, the author in [11] emphasizes that aerobic exercise alone is insufficient

for the development of executive functions – physical activity must be complex, novel, and varied, which precisely characterizes free, unstructured outdoor play. According to the summary from [12], sensory experiences gained in natural environments exert their effects through three mechanisms: they develop cognitive abilities, self-regulation, and brain executive functions. The systematic review in [13] confirms that the open-ended nature of free play in nature – in contrast to the pre-programmed interactions of digital devices – encourages children to think, experiment, and engage in creative problem-solving.

At the same time, research documents that opportunities for physical exploration are shrinking from generation to generation. The authors of [14] document a dramatic decline in independent childhood activity – including outdoor play, exploration, and risk-taking – and link this to a deterioration in children's mental well-being and cognitive abilities. According to the authors, the decline in independent activity deprives children of the experiences through which their sense of internal control and problem-solving skills develop. In [15] the authors pointed out in their pioneering synthesis that prior knowledge, including experiential knowledge-functions as a filter through which new information is interpreted; if this foundation is lacking, the new content is not meaningfully integrated.

One of the main reasons for the decline in physical experiences is the proliferation of digital devices. The systematic review of [16] demonstrated that, excessive screen time negatively affects attention, working memory, and the development of problem-solving skills, and they emphasize the irreplaceable role of tangible, physical experiences in developing critical thinking as: experimentation, tinkering, gardening. In their systematic review, [17] found in their systematic review of several studies that excessive digital media use causes structural and functional changes in the prefrontal cortex, which is the neural basis for logical thinking, planning, and executive functions directly impairing higher-order cognitive abilities. All of this supports the notion that screen time not only displaces physical experience but – through its passive consumption – actively hinders the development of the cognitive structures upon which future engineering education is built. It is also evident in the didactic literature that several universities are addressing the gradual erosion of the foundational knowledge of students entering higher education. In some cases, entire subject areas may be missing from their preparation [18], [19]. Regarding the effectiveness of active learning methods, [18] review provides compelling evidence that involving students in the learning process improves comprehension and retention of acquired knowledge. In response, diagnostic tools have been developed in engineering education to measure specific mathematical and scientific competencies, and remedial curricula have been created to address identified gaps and help students catch up.

This latter approach, which is used by the majority of instructors in higher education is necessary, but it targets only the upper, visible, and easily assessable layer of the knowledge structure; students' learning difficulties are attributed to deficiencies at this level. The reviewed literature, however, points out that students' detachment from the real world causes more fundamental and serious problems in individual thinking skills and creative work.

2.2 The Three-Layered Concept

To describe the knowledge structure necessary for successful engineering studies, we propose a three-layered conceptual model. The model consists of three vertically arranged, interrelated layers that build upon one another thematically, logically, and essentially chronologically: (i) family, society, environment; (ii) public education; (iii) engineering education (see Fig. 1).

phase	level of abstraction	example
engineering education – modeling, problem solving	abstract thinking, physical and mathematical models	beam stress analysis
public education – general intelligence	basics of sciences, concepts, laws, models	levers, moment of force
family, society, environment – motivation, engagement	perception of the real world, common sense, realistic judgment	wheelbarrow, seesaw

Fig. 1. Three-layered concept.

The foundation represents experiential knowledge gained through direct physical interaction with the real world: childhood play, physical activity, sports, manual labor, and DIY. This layer encompasses an intuitive understanding of forces, motion, materials, spatial relationships, and cause-and-effect mechanisms, which stems from experience itself. This includes what we might broadly call physical intuition or engineering common sense—the ability to form realistic expectations about the behavior of physical systems based on accumulated sensory and motor experience. In [20] experiential learning theory provides a theoretical framework for this layer: knowledge is generated as a result of reflection on direct experience. In their research, [21] confirmed, based on interviews with 17 experienced engineers, that first-hand experience is the most important source for the development of engineering intuition, which underscores the paramount importance of the experiential foundation layer; therefore, it is important to develop a testing tool designed to assess this knowledge gap among incoming students.

The second layer represents the formal knowledge acquired through systematic education: the concepts, laws, formulas, and methods taught in elementary and secondary school curricula. This includes the theoretical frameworks of the natural sciences. It is essential that the meaningful acquisition of this formal knowledge presupposes an experiential foundation: for example, understanding the concept of a single-arm lever requires prior physical experience with lifting of this kind. The knowledge presented in school lessons can only be truly understood and retained meaningfully if it is linked to experiential knowledge and lived experience. At that point, the previous conceptual framework is expanded by the new concept and anchored to real-world experience.

The top layer represents engineering modeling and specialized knowledge of technical subjects, which is built upon both an experiential foundation and a formal educational structure. Engineering education builds directly upon both of the lower layers.

The focus of thinking about engineering education is on the adequacy of the middle layer. For example, if a student cannot solve a problem related to a bicycle drivetrain, the instructor assumes that the student does not understand the concept of gear ratio or cannot calculate the wheel circumference. Meanwhile (in our experience), it is possible that the student is unfamiliar with how a traditional chain-driven bicycle works (in Hungary, where cycling is one of the most important modes of transportation).

2.3 The Erosion of the Experiential knowledge

For Generations X and Y, the experiential foundation was largely self-evident. Children typically acquired broad physical knowledge through play with wheelbarrows, seesaws, bicycles, and other mechanical objects. Sports and physical labor, as well as hands-on work with tools and materials, help build a solid foundation. The idea that a young adult beginning engineering studies would lack an intuitive understanding of such fundamental engineering concepts as the lever principle, gear ratios, or the relationship between force and motion was practically inconceivable to educators of that time.

As already discussed in Section 2.1, the proliferation of digital devices carries measurable cognitive costs. For the Alpha generation, however, the virtual environment has become the primary arena for gaining experience in the first place – not merely a competing distraction. Charan et al. in [22] describe this broader trend as the “extinction of experience”.

In our view, alongside the lack of physical experience, there is a lack of attention to real physical phenomena, as well as a lack of the need for analysis and understanding. An engineering student who cannot answer the question of where to place a crate on a wheelbarrow to lift the greatest possible weight [6], reveals not only that they have never used a wheelbarrow or a one-arm lift, but also that they have not directed their reflective attention to the mechanical principles of such everyday tools. The dominance of the virtual world leads to the disappearance of active observation of the environment. The passive recipient's perspective of the digital world does not encourage the conscious perception and interpretation of physical phenomena, so young people pass by the mechanical systems used in everyday life without any curiosity about how they work. In his study of 388 first-year students, [23] identified nine patterns of technology use and concluded that while technology influences learning habits, it does so in a non-deterministic manner—the generational narrative of "digital natives" is empirically more nuanced than the image accepted in public discourse [24].

3 Deficiencies in Experiential Knowledge

3.1 Context and Objectives

At the Faculty of Engineering of the University of Debrecen, authors of [4] conducted soft skills development (SSDM) with engineering students within the framework of specialized courses; subsequently, taking these experiences into account, the program was expanded (ESSDM) to include first-year students as well [5]. The original goal of

the program was to develop general professional competencies (communication, teamwork, problem-solving and systems thinking) within the framework of engineering studies. The pedagogical approach emphasizes the creation of realistic problem-solving situations that require students to engage with physical phenomena, apply prior knowledge and communicate their thinking within teams.

The overarching goal is to develop general engineering intelligence through the systematic review of key concepts and ideas, as well as to reactivate latent experiential knowledge related to real-world phenomena through structured tasks. While solving these tasks, we repeatedly encountered the problem that students' difficulties were not caused by a lack of formal academic knowledge, but rather by the fact that they were confronted with engineering topics for which they had no real-world experience in a physical environment; thus, in many cases, they did not even understand the question or began working based on a mistaken conceptual understanding.

The study in [25] – which synthesized 220 studies from the period between 1995 and 2020 – confirms that experiential learning is not merely a supplementary method, but an entity that can be understood within the "self-school-community" unit, and paradigm shifts have been identified in the development of experiential learning.

3.2 Formal Knowledge Testing vs Observations in Problem-solving

It should be noted that this is an exploratory, qualitative study: the tasks served as diagnostic instruments to reveal patterns of thinking, not as a basis for statistical generalization. The tasks formulated in [6] are very simple in terms of the applied mathematical and professional knowledge required; however, the prerequisite for solving them is an understanding of the outlined problem area and the ability to identify the applicable concepts and tools.

The purpose of the tests was not to assess factual knowledge, but to map the experiential knowledge essential for solving engineering problems. Since the correct solution is expected of everyone, the cases where students encountered obstacles were relevant from the perspective of the research objective. We drew our conclusions based on their comments made during team problem-solving, their logically flawed arguments, and the gaps in their experiential knowledge.

The primary purpose of traditional school tests is to assess how well students can reproduce the material they have learned.

In such a system, a student can receive an excellent grade even if they are unfamiliar with the practical manifestations of the problem at hand and merely memorize theoretical concepts and relationships. This type of preparation is insufficient for creatively solving engineering problems. When solving problems encountered in real-world settings, there is a significant difference in students' performance depending on whether they possess relevant experience or only formal knowledge of the subject matter.

Conventional entrance exams, which are widely used, are unable to predict the comprehension difficulties that instructors encounter in engineering courses. Our specialized testing method, designed to assess foundational experiential knowledge, fills this gap.

3.3 Two Test Tasks

In our method, each task covers a specific topic of varying scope. The tasks are designed so that only basic, expected formal knowledge is required to solve them. Thus, the test is not intended to evaluate performance in the conventional sense through scoring. What interests us is why those who cannot solve the task are unable to do so.

In diagnostic situations, observing the problem-solving process reveals the gaps in experiential knowledge that students who have grown up in the digital/virtual world possess, and how and to what extent these gaps hinder their understanding of engineering problems.

Since the overall goal of the studies is to improve engineering education methodology – partly by shaping perspectives and partly by developing instructional methods – in the current phase of the research, we aim to shed light on fundamental gaps that are unimaginable to the current generation of instructors.

First-year engineering students solved the tasks in teams of two, with 15–20 minutes allotted for each task.

Problem 1: Determining the parameters of the bicycle chain drive according to different specifications and calculating the bicycle's motion.

"We are equipping a 28-inch bicycle with a chain drive. For this purpose, 11-, 15-, and 19-tooth sprockets are available (several of each), which can be mounted on the pedal and rear wheel axles. (1) How should the sprockets be mounted to achieve the highest possible speed at a given pedaling cadence? (2) How should the sprockets be mounted so that the cyclist has to exert the least amount of force at a given cadence? (3) If we pedal once per second, what is the bicycle's speed in the two cases described above?"

The task was solved by 160 students in teams of two; the students had 15 minutes to complete it. We observed the team members' communication and reasoning during the problem-solving process. In addition to the solution, the teams were required to write a detailed explanation, making visible the line of reasoning that led them to the result they considered correct. We asked them to outline any questions that arose and any counterarguments.

Based on the work done in the teams and the submitted documents, three categories can be distinguished: (a) they provided a good solution; neither understanding the problem nor performing the calculations posed a problem for them; (b) they understood the problem but gave a wrong or partially wrong answer; (c) they did not understand the problem.

In our study, we analyzed categories (b) and (c). Only a small minority of the teams arrived at a fully correct solution (category (a)); the majority of the teams fell into categories (b) and (c), with category (c) – a complete failure to understand the problem – representing the single largest group among the three. This distribution, in which most teams struggled either with the solution or with understanding the problem itself, is the focus of the analysis below.

In category (c), it became apparent during the observation of the work process that many engineering students do not understand how a chain drive works, despite the fact that they regularly see bicycles equipped with such a mechanism in everyday life, and

most of them use such a vehicle themselves. Questions were also raised about whether a chainring is needed on both the front and rear axles. Several students asked why they had to solve a bicycle-related problem if they had never ridden a bicycle themselves.

The observations highlight that the dominance of the virtual world forces young people into a passive observer role; they have no need to actively observe the real world or reflect on their surroundings.

Since communication was informal during the group work, comments were made that were related but not relevant to the specific question, such as: "Are chain wheels even necessary on a bicycle?" These comments suggested that the task motivated the majority of the students to think.

Problem 2: Route selection based on the availability of nearby gas stations

"A gasoline-powered car has 2.5 liters of gasoline in its tank. The nearest gas station along the planned route is 33 km away and will close in 15 minutes. Another gas station, which is open 24/7, is accessible via a detour 42 km away. Taking the detour adds 21 km to the trip. Furthermore, if the driver turns back, there is a 24-hour gas station 7.5 miles away (Fig. 2(a)). Considering the car's fuel consumption curve (Fig. 2(b)), which gas station should the driver choose if the goal is to keep the total distance traveled as short as possible?"

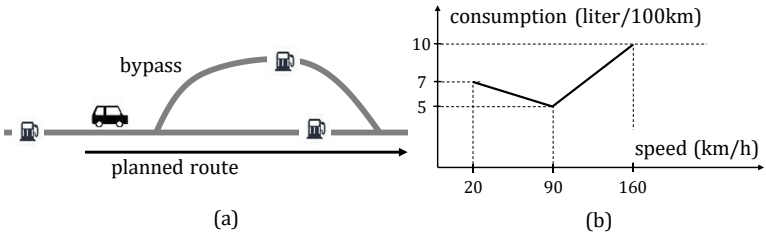


Fig. 2. Schematic map with the possible routes (a) and the fuel consumption diagram (b)

Understanding the concept of fuel consumption is key to solving this problem, as is understanding Fig. 2(b), which shows how fuel consumption depends on speed. Additionally, you must understand the relationship between time, distance traveled, and speed.

When solving the problem, one must first determine whether the vehicle can reach the gas station along the route. If not, one must then check whether the vehicle can reach the two alternative gas stations. If it can reach both, one must choose the one that results in the shorter total distance traveled.

The task was completed by 222 students in teams of two, with 20 minutes allotted. The submitted answers here also contained surprising elements that went beyond the formal computational difficulty.

A significant portion of the teams could not interpret the consumption diagram and did not know how to use it. Only a small minority of the teams arrived at a fully correct solution, correctly combining the reachability check with a correct reading of the speed-dependent consumption diagram. A further, somewhat larger group reached a partially

correct solution, typically managing the reachability check but struggling with the consumption diagram itself. The largest group of teams, however, failed to follow a coherent line of reasoning altogether, indicating that the underlying logic of the problem – not merely the diagram – remained unclear to them.

Those who could not even take the first step undoubtedly sought to restructure the problem's conditions to relieve the frustration and stress arising from its difficulty, and constructed answers aimed not at solving the given problem but at circumventing it. Some students asked whether the road was sloped, in which case they could coast to the gas station even in neutral. Others asked if they could push the car if the gas station was already "close by."

These comments suggest that the students engaged with the problem, but they lacked an understanding of speed-dependent fuel consumption, which would be expected of an engineering student.

4 Discussion

The observations presented point to a category of knowledge gaps whose examination and treatment differ greatly from the analysis of gaps in school-based knowledge. Based on this three-layered concept: while the gaps in the second layer of formal education – a forgotten formula, concept, or relationship – are relatively easy to identify and, in most cases, address, the instability of the foundational layer is much harder to detect. Instructors of engineering subjects understandably do not expect a student to be unable to optimally position a load on the platform of a wheelbarrow so that it is easiest to lift [6], or to understand how a chain drive works. These elements of knowledge were previously acquired as natural parts of everyday life, through childhood play and physical activity. Since educators do not anticipate such a gap in students' experiential foundation, they do not even ask about it, and thus no diagnostic tools have existed to identify it. Consequently, student difficulties are routinely attributed to gaps in formal knowledge – the visible, testable layer – while the true cause lies in the invisible experiential foundation.

According to our findings, the comprehension problems observed in engineering education have two sources. One is a lack of formal academic knowledge, which is the focus of traditional remedial efforts. The other (less researched and addressed) cause is the lack of knowledge derived from direct, firsthand experience of the physical world through one's own eyes and hands. From the perspective of educational effectiveness, the latter poses a greater problem because it remains unrecognized. It is possible that a student who successfully recites the theoretical definition of a lever cannot solve a practical problem because they have never experienced how the required force changes with the length of the lever arm. Experiential knowledge does not merely supplement formal knowledge; it must form the basis of conceptual understanding for engineers.

The shortcomings discussed in this article cannot be classified as the "soft skills" frequently discussed in the literature today, but they play an important role in laying the groundwork for them. A background in the natural sciences and common sense based on realistic judgment foster effective comprehension and reasoning skills, as well

as innovative thinking. Rather, the experiential foundation precedes and underlies the development of soft skills: without realistic physical intuition, the communication, problem-solving, and systems-thinking abilities targeted by soft-skills programs lack the common-sense substance they are meant to operate on. In this sense, experiential knowledge is a prerequisite for, rather than a component of, soft skills.

The lack of experiential knowledge affects the day-to-day reality of engineering education. Addressing this requires an appropriate diagnosis, which can be achieved, on the one hand, by assigning the specialized tasks we propose, and on the other hand, by designing student engineering projects based on pedagogical principles. Introductory engineering courses could incorporate short, hands-on tasks built around everyday physical objects – for example, determining where to place a load on a wheelbarrow, comparing gear ratios on a bicycle, exploring friction with simple sliding blocks, or measuring the period of a swinging pendulum. Such tasks require minimal equipment and time, yet they directly target the missing experiential layer rather than formal knowledge.

Opportunities for direct engagement with phenomena of the physical world must be systematically integrated into education at both the secondary and higher education levels. Based on the experiences presented, we must go down to a level as simple as using a wheelbarrow or a bicycle. As the degree of detachment from physical reality increases, more and more people will need this. The effectiveness of learning engineering subjects can be significantly improved by presenting the fundamental ideas mentioned.

We must raise instructors' awareness through teacher training: if they recognize that students' difficulties may stem not necessarily from a lack of knowledge of the subject matter, but from a lack of experience with the physical world, they will be able to provide more effective pedagogical responses. As a next step, we plan to develop a standardized evaluation framework for these diagnostic tasks, enabling systematic comparison across cohorts and institutions.

According to our experience, many students encounter real-world problems for the first time in engineering education, which require common sense and creativity based on real-life experience. There is no question that deficiencies should be detected and addressed at an earlier age in public education. Our results highlight a problem that needs to be addressed. In summary, the main contributions of this study are threefold: (1) we propose a three-layered conceptual model that separates experiential knowledge from formal school knowledge and engineering-level abstraction; (2) we provide qualitative evidence, from diagnostic tasks administered to first-year engineering students, that a substantial share of problem-solving difficulties stem from missing experiential knowledge rather than missing formal knowledge; and (3) we argue that this hidden layer requires new diagnostic tools and pedagogical responses, distinct from the remediation methods currently used for formal-knowledge gaps.

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