

Making Equations Speak: Communicating Mathematical Models Across Engineering Disciplines

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ABSTRACT

In engineering programmes, mathematical modelling is usually introduced as a bridge between theory and the real physical world. In practice, however, many undergraduates still treat equations as something to be solved rather than something to be understood. They are often able to follow the algebraic steps, but they struggle to explain what those equations are actually saying about motion, energy, current, or force. This paper looks at that problem from a communication point of view. The discussion in this paper is based on the teaching experience of three instructors who have each taught mathematical modelling in both mechanical and electrical engineering courses at Universiti Teknikal Malaysia Melaka. Over several years of working with undergraduate engineering students, similar patterns kept appearing: students could “do the maths”, but they could not confidently describe what the terms in the model meant in physical terms. We reflected on these recurring situations using informal classroom observations, short student feedback, and adjustments made during live teaching. From that reflection, we identified typical barriers that block understanding, such as students’ habit of seeing equations only as calculation procedures, or lecturers’ habit of delivering explanations in one direction. We also describe three teaching moves that repeatedly helped: (i) using analogy and short narrative to make an equation feel like a story of cause and effect, (ii) showing behaviour visually in real time, and (iii) encouraging students to talk through meaning, not just provide answers. These three moves are then organised into a simple communication framework with three stages: translation, visualisation, and dialogue. The aim of the framework is to help students link symbols to physical behaviour in a way that feels concrete to them, regardless of whether the system is mechanical or electrical. The paper argues that mathematical modelling is not only a technical skill but also a language that needs to be spoken, shown, and discussed. Clearer communication can help students read equations with understanding, not only manipulate them. The work ends by suggesting that engineering educators and curriculum planners should treat communication as part of core modelling instruction, not as something optional.

Keywords—mathematical modelling, engineering education, conceptual understanding, communication in STEM.

INTRODUCTION

When we teach engineering, we often tell students that “the model represents the system.” In other words, an equation is not just mathematics; it is a description of how something in the real world behaves. A model should help us talk about how a machine vibrates, how a fluid responds to pressure, or how an electrical signal changes with time. In theory, this is central to engineering education. In day-to-day teaching, the story is more complicated.

Many students still see equations as steps to follow and numbers to substitute. They do not always see that a mathematical model is basically a compressed explanation of reality. This is not limited to one subject area. In mechanical classes, for example, we may write down the standard second-order model for a mass–spring–damper and talk about inertia, damping, and stiffness. In electrical classes, we may write the corresponding form for an R–L–C circuit and talk about resistance, inductance, and capacitance. To us, as instructors, these two systems feel almost like twins: they share the same mathematical “shape”. But a lot of students do not immediately see that connection. They treat each topic as something new, rather than recognising that it is actually the same story told in a different physical language.

Over several semesters of teaching modelling and basic system dynamics in both mechanical and electrical contexts, we kept noticing the same behaviour. Many students could rearrange formulas and perform algebraic manipulation correctly. They could differentiate, integrate, and solve for an unknown constant when asked. But when we asked a different kind of question, such as “What does this term represent physically?” or “If this parameter increases, what will actually happen to the motion?”, some of them hesitated. The confidence they had while calculating did not always transfer into their explanation.

This points to a deeper gap. On the surface, it looks like a mathematical problem, but in reality, it behaves like a communication problem. Research in engineering education has also described this tension between symbolic skill and conceptual understanding [1]. When the learning experience is dominated by copying equations from slides or notes, many students start to believe that “doing well” means following procedures fast, instead of understanding what the model is trying to say about the system.

Traditional lectures, if we are honest, can make this worse. A lecture that moves quickly through derivation steps can become a one-way transmission. The lecturer talks, the students copy, the page fills up with symbols, and everyone feels busy. But being busy is not the same as understanding. We have personally seen situations where a student can reproduce the full derivation of a transfer function, line by line, and yet cannot tell us what parameter is responsible for slowing the motion down, or what term is responsible for energy loss in the system. In short, the “what” (the formula) is there, but the “why” and “how” are not yet alive in the student’s mind.

The purpose of this paper is to reflect on that specific problem and to frame it in terms of communication. We are not claiming that mathematics is unimportant. In fact, mathematics remains a fundamental element in engineering. What we are asking is how the way we talk about equations, present equations, and discuss them can make those equations easier for students to interpret. In simpler terms, how can we make equations speak?

This paper has three aims:

1. To describe where communication tends to break down when we introduce mathematical models in early engineering courses.
2. To highlight classroom strategies that seemed to help our students connect symbols to physical meaning.
3. To propose a simple communication framework that can be applied across disciplines such as mechanical engineering and electrical engineering.

A large body of work already supports the importance of modelling in engineering education, and many authors have discussed active engagement, visualisation and conceptual development [1][2][3]. However, our focus here is slightly different. We are interested in how meaning is communicated at the moment of teaching. For example, the words used to introduce a new model, the visual supports used to show behaviour, and the way we invite students to talk back. We believe this communication layer is often underemphasised in classroom practice, even though it clearly affects whether students internalise the model as something physical or memorise it as something abstract.

The next section reviews related work in two main areas: (i) mathematical modelling in engineering education, and (ii) communication and pedagogy in engineering classrooms. That review provides context for the reflective method we later apply in this paper.

LITERATURE REVIEW

Mathematical Modelling in Engineering Education

In engineering, the idea of using a mathematical model is simple: we take a complicated physical system, and we express its essential behaviour in mathematical form. That form may be a differential equation, a transfer function, or a state-space description. Once we have that representation, we can predict behaviour, analyse stability, design controllers, and so on. In other words, the model is a tool for thinking.

Even so, studies have repeatedly reported that many students treat modelling work as a purely procedural task. They “follow the steps”, but they are not fully convinced that the equation is telling a physical story [1][2]. Wankat and Oreovicz describe how engineering students sometimes lean on memorised solution patterns rather than genuine reasoning, especially under time pressure [2]. Lyon and Magana observed that students can often execute calculations without being able to interpret what those results mean in terms of physical behaviour or design decisions [1].

Some authors argue that the difficulty is not because the mathematics is too advanced. The difficulty appears because of how the mathematics is framed in class. Felder and Brent point out that when instructors present equations without enough physical context, students naturally fall back to memorisation [3]. In other words, students do what they are rewarded to do: they learn the steps that will get them marks, even if they do not really “see” the system behind the symbols.

There is also encouraging evidence. Magana and colleagues note that when students are allowed to experiment with simulation tools and model-based activities, they start to link the mathematical form to actual physical response [4]. Instead of just reading an equation, they watch the system respond on screen. This helps them answer questions like “What happens if damping increases?” not only in words, but by pointing at a graph and saying, “See, it settles faster now.”

Dori and Belcher found similar outcomes in electromagnetism classes, where visual and interactive delivery, rather than the traditional chalk-and-talk approach, helped students connect abstract field equations to something they could imagine more concretely [5]. Although the content is different (electromagnetism versus, say, mechanical vibration), the underlying challenge is familiar: how do we get students to feel that the math is describing something real?

Communication and Pedagogical Strategies in Engineering

When we use the word “communication” here, we are not only talking about speaking clearly or writing nicely. We are using communication in a broader sense: helping students see meaning. In engineering practice, experienced engineers are often described as people who can “translate” a complex technical idea into language that other people can understand [6]. A similar responsibility exists in teaching.

Several well-known learning frameworks describe why this matters. The ICAP framework by Chi and Wylie explains that deeper learning is more likely when students are not just listening, but actually generating, discussing, and explaining ideas to themselves or to others [7]. Freeman and co-authors summarise broad evidence across STEM disciplines showing that active learning improves student performance compared to purely passive lecture formats [8]. Put simply, when students are invited to talk about what the equation means, instead of only copying it, they learn more.

Visual communication is another important element. Classic work in control systems education already recognised that sketches, block diagrams, and response plots are powerful because they make invisible relationships visible [9]. When students see a step response curve change because a parameter changed, it becomes easier for them to link a symbol in the equation to an effect in the real (or simulated) system. This fits with multimedia learning principles, where suitable visual and verbal channels together can strengthen understanding [17].

Reflection also plays a role. Kolb's experiential learning cycle and Gibbs' reflective cycle both emphasise that understanding is built through repeated cycles of doing, observing, and thinking about what happened [10][12]. Prince and Felder discuss inductive approaches in which students are first given a problem or observation, and then guided towards the concept, rather than the other way around [13]. This shifts the classroom energy: instead of starting with the algebra and asking students to accept it, we can start with behaviour ("Look at how this system oscillates") and then bring in the algebra to explain it.

The present paper takes these ideas and applies them to the specific act of teaching mathematical models to early-stage engineering students. The next section explains how we approached this analysis.

METHODOLOGY: REFLECTIVE PRACTICE APPROACH

This paper uses a reflective practice approach. The purpose is not to test a hypothesis in a controlled experiment, but to analyse what repeatedly happens in real classrooms and to make that analysis explicit. The reflections reported here are drawn from three instructors at Universiti Teknikal Malaysia Melaka. Two of us teach mainly in mechanical engineering programmes, especially topics like system dynamics, modelling of mechanical elements, and introductory control concepts. The third teaches in electrical engineering, including topics that deal with current flow, dynamic response of circuits, and control-related thinking applied to electrical systems.

Each instructor has taught mathematical modelling and system behaviour for more than five years. Across that period, we taught different cohorts, different intakes, and slightly different syllabi. Yet the same teaching difficulty kept appearing: students could carry out manipulation of equations but hesitated or felt uncomfortable when asked to interpret what those equations meant physically. That persistent pattern became the motivation for this reflection.

Sources of Reflection

We based our reflection on three informal but consistent sources of evidence from our classrooms:

1. Observation during lectures and tutorials. While teaching, we paid attention to students' body language and facial reactions at the point where an equation was first introduced. For example: did they lean forward and follow, or did they freeze the moment the symbols appeared?
2. Short informal feedback. At the end of some sessions, we asked simple questions such as "Which part felt most abstract today?" or "Which part felt easy to imagine?" These were not formal surveys, but quick check-ins that gave us a sense of where the explanation was (or was not) landing.
3. Live adjustment during teaching. Over time, we noticed that we were actively changing how we spoke about certain models. Sometimes we would pause and add an everyday analogy. Sometimes we would sketch a simple diagram or run a fast simulation just to show behaviour. We treated these small adjustments not as random improvisations, but as deliberate attempts to improve conceptual clarity.

To illustrate, one recurring example came from early sessions on mass-spring-damper systems. At first, many students could write the governing equation correctly but gave vague answers when asked, "What will happen to the motion if damping doubles?" After we applied the three-stage approach, students began to describe the same situation more vividly, using words such as "the motion calms faster" or "less vibration happens before it stops." Similar changes appeared in electrical circuit lessons, where students began to describe energy flow between capacitor and inductor using physical metaphors. These short, anonymised classroom moments provide qualitative support for the reflective insights reported in this paper.

These reflections were drawn from multiple semesters and courses taught independently by the three instructors over several years. Although the teaching contexts were not continuous or identical, all of us encountered comparable patterns while introducing mathematical modelling topics. The reflections were recorded informally through teaching notes, post-lecture discussions, and recollections of recurring classroom situations. Rather than representing data from a single cohort, this collective reflection represents converging observations gathered across different classes, disciplines, and academic years. The consistency of these patterns across separate

experiences gave us confidence that the communication barriers and teaching responses described in this paper are not isolated, but recurrent and generalisable within our context.

Focus of Analysis

We then organised these classroom notes around a single question: Which parts of our communication seemed to help students move from “I can calculate” to “I understand what this means physically”? From this question, three recurring elements stood out. First, we often needed to “translate” the symbols into plain physical language before doing anything else. Second, we needed to “visualise” the behaviour, usually with a plot, a diagram, or a quick simulation, so they could literally see what the parameters do. Third, we needed to open space for “dialogue”, meaning we had to ask students to explain back what they thought was happening, not only answer numerical questions.

We eventually began referring to these elements as the three stages of a simple communication framework: translation, visualisation, and dialogue. This way of organising things is consistent with ideas from constructivist and experiential learning theory [10][11]. Those traditions argue that students build understanding by connecting language, imagery, and interaction — rather than receiving content passively.

The next section presents what we observed in our classes and how those observations connect to the three-stage framework.

FINDINGS AND DISCUSSION

Communication Barriers Observed

Across both mechanical and electrical settings, we kept seeing three recurring barriers.

1. Symbols without physical meaning. Students were often comfortable manipulating mathematical expressions, but less comfortable linking each symbol to something physical. Take a standard second-order system model from a mechanical system consisting of a spring, mass, and damper. We might point to the mass term (which represents inertia), the damping term (which represents energy loss or resistance to motion), and the stiffness term (which represents how strongly the system tries to return to equilibrium). Many students could name those terms correctly. But when we asked, “So, in words, how does damping affect the motion over time?”, they struggled to answer in a clear, confident sentence. A very similar pattern appeared in introductory electrical modelling. Terms such as resistance, inductance, and capacitance were sometimes treated as just “numbers to plug in”, rather than as physical properties that shape how current and voltage change [14].
2. Equation-first learning. A second barrier is the habit of starting from the equation instead of starting from behaviour. Quite often, students begin by rearranging formulas before they have a mental picture of what the system is doing. In our experience, this reverses a natural order. If students cannot yet imagine how the system behaves, then the algebra they are doing feels disconnected. They end up memorising methods without building intuition.
3. One-way communication. A third barrier is one-way communication in the classroom. If the flow of teaching is mostly lecturer → student, with very little student → lecturer, then misunderstandings can survive for a long time without being noticed. We saw cases where students maintained incorrect conceptual pictures for weeks, since one-way teaching left little space for those misunderstandings to be revealed. This is serious, because weaknesses in students’ foundational understanding often carry forward and influence their performance in later engineering courses [15]. Put another way, if “damping” is memorised only as a formula without understanding its physical meaning, that misconception can persist and reappear in more advanced courses, even during final-year design projects.

These three barriers are consistent with previous reports that engineering students sometimes try to “do the maths” before they have really built the concept [16][6].

Effective Communication Strategies

Based on the reflections, three main teaching strategies were found to help bridge the communication gap between symbols and meaning.

- (a) Using Analogical Narratives. Instead of jumping directly into a formal derivation, we sometimes started with a short story or comparison. For a mechanical system, we might describe the model in terms of a car suspension reacting to a bump. For an electrical system, we sometimes describe a capacitor as if it is “breathing” energy in and out of the circuit. These are not perfect scientific descriptions, and we tell students that clearly. But the analogy gives them a first mental handle. It turns each mathematical term into “the part that resists motion”, “the part that stores energy”, “the part that pulls back to centre”, and so on. Earlier work has shown that multimodal explanation and technology-supported visualisation can make abstract topics like electromagnetism feel more physically grounded [5]. Trevelyan also links this kind of translation skill to how engineers communicate in practice [6].
- (b) Visualisation and Real-Time Demonstration. Very often, when students watched a simulation output change in front of them, understanding improved. For example, if we increased damping in a model and immediately plotted the new response curve, students could point to the graph and say, “Now it settles faster, with less oscillation.” Software tools such as MATLAB and Simulink are useful here because they let us change parameters and instantly redraw the system response. This supports what Magana and colleagues observed: simulation-based engagement helps students see mathematical models as descriptions of behaviour, not just as symbolic objects [4]. It also connects with multimedia learning research, which argues that visual and verbal channels can reinforce one another [17].
- (c) Dialogic Questioning and Feedback. We deliberately asked questions that forced students to express meaning, not only to compute. Examples include:

“If we make the damping larger, what happens to the motion, in plain language?”

“In this equation, which part is responsible for energy loss, and why?”

“If we reduce resistance in the electrical model, what kind of response do you expect to see?”

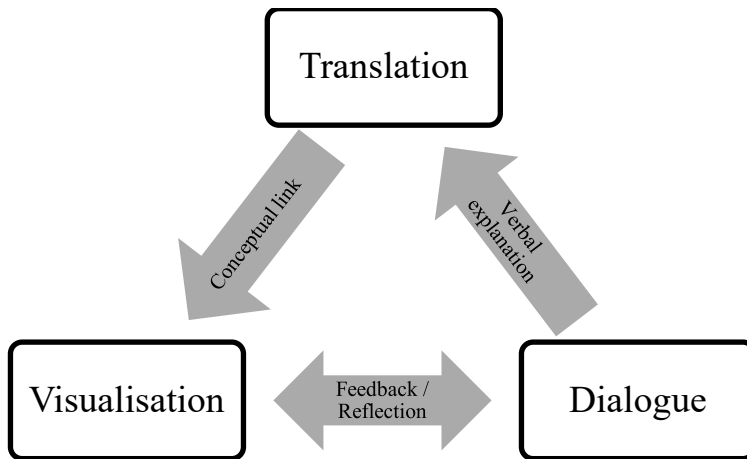
These questions opened up short discussions among students. Very often, one student would explain to another in everyday language, and we saw confidence rise. This approach lines up with active learning literature, which shows that involving students in reasoning and explanation leads to better performance and retention [7][8].

The Three-Stage Communication Framework

Although each of the strategies described above can be applied independently, we found that the process became clearer and easier to teach to new instructors when we organised the ideas into a simple three-stage sequence consisting of translation, visualisation, and dialogue, as shown in Fig. 1. The idea is straightforward:

1. Stage 1 (Translation): First, we “translate” each key mathematical term into physical language. For a mechanical model, we might say, “This term represents inertia or mass, which resists sudden changes in motion. This term represents damping, which causes energy to dissipate. This term represents stiffness, which restores the system toward equilibrium.” For an electrical analogue, we would match those roles with inductance, resistance, and capacitance. The goal here is to build a physical picture before moving into more complex algebraic work.
2. Stage 2 (Visualisation): Next, we show what those terms do by plotting, sketching, or simulating. For example, we demonstrate how increasing damping changes the time response: the oscillation dies out faster, or the overshoot becomes smaller. Students are not just told “damping reduces oscillation”; they watch it happen.
3. Stage 3 (Dialogue): Finally, we ask students to explain what they think is happening, using their own words. We encourage them to compare mechanical versus electrical interpretations. At this stage, we try not to dominate the conversation. Instead, we guide and correct as needed.

Fig. 1. The Translation-Visualisation-Dialogue Framework.



In practice, we often used something like an informal table or checklist to remind ourselves what to emphasise in each stage:

1. Stage 1 (Translation): Link symbols to physical meaning (“This term is the ‘resistance to motion’ part”).
2. Stage 2 (Visualisation): Make the behaviour visible (“See how the curve changes when we adjust this parameter”).
3. Stage 3 (Dialogue): Get students to speak that meaning aloud (“Tell me which term controls energy loss here”).

This simple structure gave us a common language as instructors. It also helped students realise that “understanding an equation” is not only about being able to rearrange it. It is also about being able to describe, to see, and to discuss. This aligns with long-standing calls in engineering education to balance rigour with clarity and to treat conceptual understanding as something we actively cultivate, not something we assume will appear automatically [9][10][11][13].

Educational Implications

Looking across these reflections, one message keeps repeating: communication itself is not just decoration. It is part of the core technical work of teaching mathematical models. The way we introduce an equation, the way we illustrate its behaviour, and the way we invite students to speak about it all play a vital role in shaping how they internalise the model.

This communication-oriented approach aligns with ideas from the Discourse of Engineering Practice (DEP), where professional meaning-making depends on engineers’ ability to translate between mathematical, visual, and verbal modes [20]. In the classroom, the same discursive shift occurs when students learn to explain what equations “say” about the system, not merely compute their solutions. Similarly, Situated Learning Theory [21] suggests that knowledge develops through participation in authentic practices. The Translation-Visualisation-Dialogue process mirrors such authentic learning by engaging students in the communicative reasoning typical of real engineering problem solving.

Within the Malaysian context, this framework also complements Outcome-Based Education (OBE) practices promoted by the Engineering Accreditation Council (EAC) and the Engineering Technology Accreditation Council (ETAC). Both councils emphasise communication as one of the key Programme Outcomes for engineering and technology graduates, alongside problem-solving and lifelong learning. Recent local research among Malaysian public universities found that engineering students perceive courses designed to develop Graduate Success Attributes as essential platforms for strengthening their communication abilities, particularly in speaking and building self-confidence [22]. Embedding communication within modelling instruction therefore supports the goals of continuous improvement and graduate attribute development outlined in Malaysia’s OBE-oriented engineering curricula.

The three-stage framework is deliberately simple, which makes it adaptable. We used it in mechanical vibration topics (mass–spring–damper), and we also used it in electrical circuit topics (R-L-C response). Even though the physical objects are different, the communication process felt the same. This supports the idea that mathematical modelling can be taught as a kind of shared language that cuts across sub-disciplines [14][18]. When students notice that “this pattern of behaviour” exists in both mechanical and electrical systems, it strengthens their sense that engineering knowledge is connected, not fragmented.

From a wider education perspective, this reflection also supports the argument that teaching should itself be reflective. That is, instructors should pay attention to how students are making sense of what is taught, and then adjust their communication style when needed. Prior work in engineering education suggests that reflective, iterative teaching practice contributes to stronger conceptual development and professional thinking in future engineers [3][10][11][19]. We see our framework as one practical way to operationalise that idea.

Finally, this has implications for confidence. When students understand why an equation looks the way it does, they usually become less afraid of it. Equations feel less like mysterious objects and more like tools they can handle. We observed that this shift in mindset encourages deeper reasoning, not only in solving numerical problems but also in discussing system behaviour in design or troubleshooting situations.

LIMITATIONS AND FUTURE WORK

While this reflection offers insight into common communication barriers and practical strategies, it also has limitations. The analysis is based on reflective teaching notes and informal student feedback, not on controlled experimental data. Therefore, generalisability remains limited. Future work will focus on conducting a structured student perception survey to evaluate how the Translation-Visualisation-Dialogue approach influences students’ engagement, confidence, and conceptual understanding across different courses. The survey findings will help to identify which parts of the framework, namely translation, visualisation, or dialogue, have the strongest effect on students’ comprehension and motivation.

CONCLUSION

For many engineering students, equations initially appear as long strings of unfamiliar symbols. If those symbols are presented without context, they can feel cold and disconnected. But when we slow down and explain what each term is doing in physical language, when we show how the system behaves, and when we ask students to talk through that behaviour, the same equations begin to act like explanations instead of obstacles.

In this paper, we reflected on our teaching practice and proposed a simple three-stage communication framework: translation, visualisation, and dialogue. The intention of this framework is not to replace mathematical rigour, but to support it. Translation helps students attach physical meaning to each symbol. Visualisation helps them see how a change in one parameter affects the actual response of the system. Dialogue invites them to test their understanding out loud and to listen to how their peers interpret the same model.

Across mechanical and electrical topics, we saw that this approach helps students answer questions such as “Which part of this model represents energy loss?” or “What will happen to the response if damping increases?” with more confidence. In our view, that confidence matters. It encourages students to move from purely procedural work (“I can solve for x ”) toward conceptual reasoning (“I understand what x represents and why it matters”). This shift is important for developing engineers who are not only able to calculate, but also able to explain and justify design decisions.

We suggest that future work should prioritise a structured student perception survey to evaluate the TVD approach across courses, focusing on how translation, visualisation, and dialogue differentially influence engagement, confidence, and conceptual understanding. Even without formal testing, our classroom experience already points in one direction: mathematical modelling in engineering is not only about mathematics. It is also about communication. When equations are treated as part of a conversation, students are more willing to listen to them.

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