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Three Models and Engineering Analysis

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Three Model Framework for Engineering Problem Solving

Abstract

A three-model framework provides a foundation and context for developing engineering analysis skills. The three models are 1) reality, 2) mental models, and 3) engineering and math models. A diagram of these models supports the engineering problem solving format (*Given, Find, Procedure, Solution, Answer*) and illustrates the interaction between engineering application (reality), engineering judgement (mental model), and scientific theory (engineering/math model). Engineers work with each of these models as they develop their understanding of a concept or solve a particular problem. Reality is the way the world actually works; in general, reality tends to be complex. The engineer works to shape reality, and therefore, must be a student of reality, learning how the world works through thoughtful observation. As engineers consider reality, they build mental models of how the world works. The mental model is qualitative and often intuitive. The mental model is the single greatest asset an engineer has; in the qualitative and intuitive world of the mind creativity flourishes. An engineer who wishes to communicate or refine a mental model will draw sketches or diagrams. The mental model should lead to the proper selection of an engineering/math model. Engineering/math models are often the primary focus of the formal classroom. These models are quantitative and lead to numerical predictions of various outcomes. However, engineering/math models, by nature, require simplification; the mental model must make and check the assumptions required to build a solvable engineering/math model. The engineering/math model is usually expressed using logic and mathematics; often computers facilitate numerical predictions. Active integration of the mental model and engineering/math model equips the engineer to properly shape reality.

Note

This paper is being submitted to the Civil Engineering Divisions “Best in 5 Minutes: Demonstrating Interactive Teaching Activities” session. It is not intended to be a research paper, rather it describes a useful framework for classroom instruction.

Keywords

Problem Solving, Mental Models, Classroom Demonstration

Introduction

Engineering students often enter the college classroom with a mindset that looks at a class and its content as unconnected with the world or with other classes. Though some students may enter college primarily to acquire a certification, most students desire to learn. However, they frequently lack an intellectual framework for internalizing and synthesizing the content of a given class. Many frameworks can help students better understand their educational experience and how they might best integrate classroom activities with other learning opportunities [1]. For example, fixed vs growth mindset, Bloom's taxonomy and the classical model of education each provide a way of considering the learning experience [2]–[4]. The three-model framework described here provides a generalized perspective to support the development of engineering problem solving skills. The three models are 1) reality, 2) mental models, and 3) engineering/math models. The diagram of these models in Figure 1 illustrates the interaction between engineering application (reality), engineering judgement (mental models), and scientific theory (engineering/math models). Engineers work with each of these models as they develop their understanding of a concept or solve a particular problem.

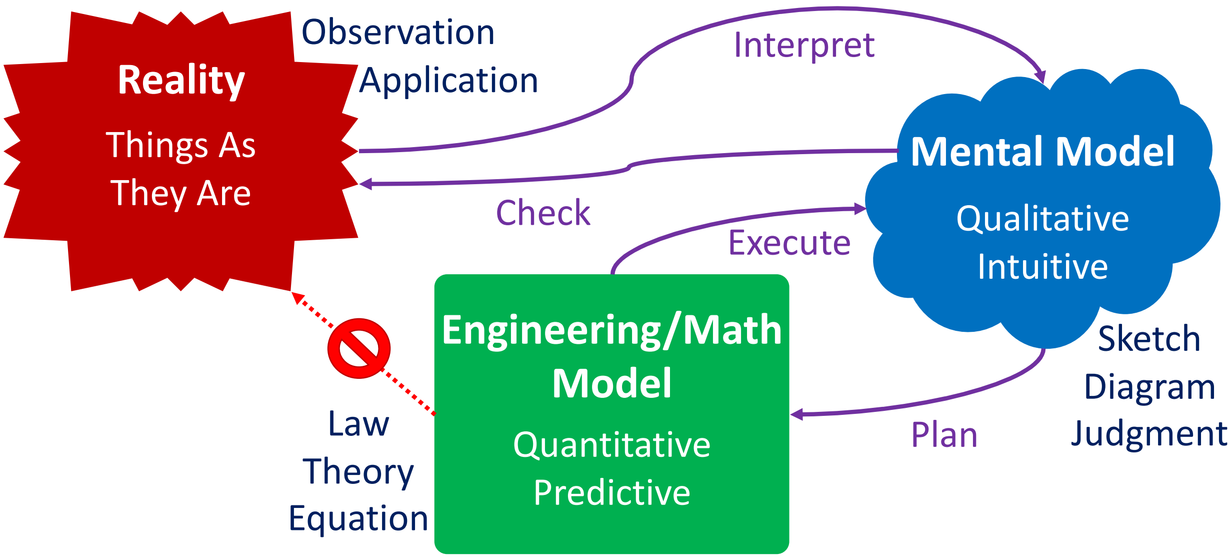

Figure 1. Diagram of the three-model framework.

Models

Reality

The first model an engineer must engage with is reality. Engineers of all disciplines fundamentally work to shape reality in such a way as to solve particular problems. Engineering application requires the engineer to consider the way the world actually works. Every engineering application must move out of the safe world of the theoretical into the real world to be truly useful. Figure 2 shows the representation of reality as typically sketched on a white board in the classroom.

Figure 2. A graphical representation of reality: jagged and rough, experienced through observation, shaped through engineering application.

The challenge for the engineer is that reality tends to be complex. The created world is full of the jagged unknown, and the unexpected consequence makes the engineer's work challenging. Reality will respond as it will, and reality simply does not ask the engineer for permission. Be it the soil between borings for the geotechnical engineer, the construction imperfections for the structural engineer, changing demands of weather for the environmental engineer, or the unforeseen expectations of the public, reality will do what it will do.

The engineer must learn to work with reality, not fighting or denying it. In order to do so, the engineer must be a student of reality by thoughtful observation. This is why students take laboratory classes and review case studies; before engineers work to shape reality, they must observe reality and develop mental models of reality.

Mental Model

The mental model is where the engineer is most able to develop innovative solutions to reality's problems. As engineers consider reality, they build mental models of how the world works. Mental models allow the engineer to consider a problem and qualitatively identify the outcome of a particular solution. The intuitive understanding of reality found in a strong mental model is key to developing good engineering judgement [5]. The mental model is the single greatest asset an engineer has; in the qualitative and intuitive world of the mind creativity flourishes. Figure 3 shows the representation of the mental model as typically sketched on a white board in the classroom.

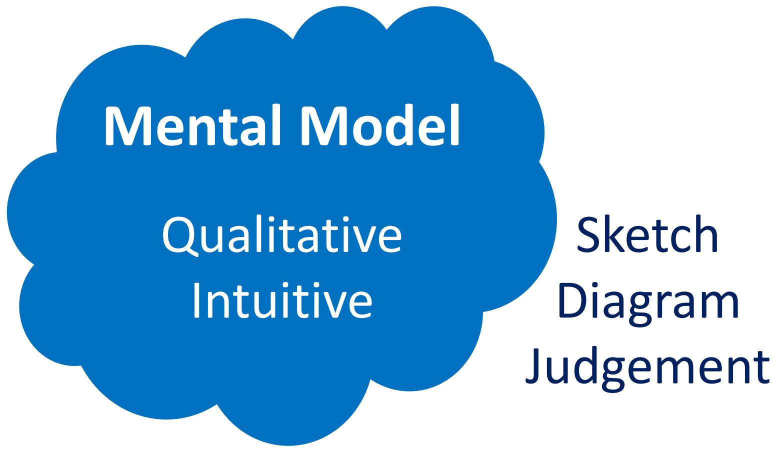

Figure 3. A graphical representation of the mental model: fluffy and in the mind, communicated through sketches and diagrams, the wellspring of engineering judgment.

Everyone has mental models. Consider playing basketball. Anyone who has spent time shooting hoops knows the feeling of the ball leaving their hands only to immediately know that the shot has missed both hoop and backboard. Embarrassment sets in, even as reality is still working out the implications of a badly missed shot.

A strong mental model is not directly teachable. Instructors cannot simply hand the student their own internal understanding of the world. The instructor can help, with words, equations and diagrams; but fundamentally, developing a strong mental model and the engineering judgement that goes with it requires careful observation of the first model, reality [5]. By seeing and considering the behavior of the world, daily and continually, the engineering student can become a competent practicing engineer. Where the engineering student cannot experience firsthand, he must learn to experience second hand through the careful reading, digesting, and internalizing of the lessons taught by instructors, the experiences shared by supervising professional engineers, and the carefully documented case-studies and reports of the engineering community.

The engineer who wishes to describe, share or even refine a mental model will most often turn to the sketch pad. Where the engineer interacts with reality by observation and application, the diagram or sketch is the means of engaging the mental model and refining engineering judgment [5]. Why do engineering students take engineering drawing or computer aided drafting early in their academic curriculum? Is it not so they can develop and express their mental models clearly? Why does every statics problem start with a free body diagram? The engineer must know what forces are at work in their mental model before doing any math. Only after the engineer has a strong mental model can they select the appropriate engineering/math model.

Engineering/Math Model

The final model is the engineering/mathematical model. Engineering/math models are often the primary focus of the formal classroom. Engineering/math models consist of scientific theories, laws, relationships, procedures, design tables and algorithms. Engineering/math models are quantitative and lead to numerical predictions of various outcomes. If mental models are qualitative and intuitive, engineering/math models are quantitative and predictive. If reality is jagged, and mental models are fluffy, then engineering/math models are clean and simplified. Figure 4 shows the representation of the engineering/math model typically sketched on a white board in the classroom.

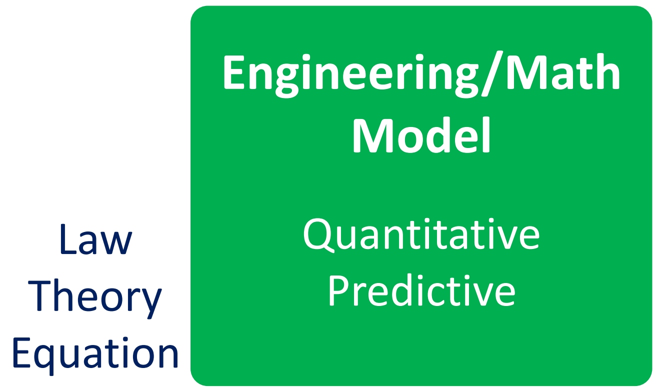

Figure 4. A graphical representation of the engineering and math model: rigid and simplified, consisting of laws and equations based on scientific theory.

The development of any engineering/math model involves simplification and estimation; the mental model must make and check the assumptions required to build a solvable engineering/math model. In an attempt to predict reality, the engineer uses a mental model to identify those factors that must be considered in an engineering/math prediction and what factors can be ignored while maintaining conservatism. Alternatively, the engineering student can also use engineering/math models to inform the mental model. Often in the engineering classroom, the instructor shows an equation or describes a scientific principle with the goal of shaping a mental model even as he or she describes an engineering/math model.

The engineering/math model is usually expressed using logic and mathematics; often computers facilitate numerical predictions. A set of engineering calculations is the engineering/math model worked out to a quantitative solution. Too many students consider this to be the central task of the engineer. The outcome of an engineering/math model must then be evaluated by a strong mental model before any true claim might be made about reality.

The engineering student can use the three-model framework to differentiate between the engineering/math model and the mental model; he or she can learn to consider the reality that an engineering/math model is intended to simplistically represent. All three models must be taken into consideration when solving engineering problems.

Problem Solving

As the engineering student learns to solve problems, the interaction between the three models lead naturally to engineering problem solving format. Figure 5 shows the engineering problem solving format (*Given*, *Find*, *Procedure*, *Solution*, *Answer*) and illustrates its interaction between engineering application (reality), engineering judgement (mental model), and scientific theory (engineering/math model).

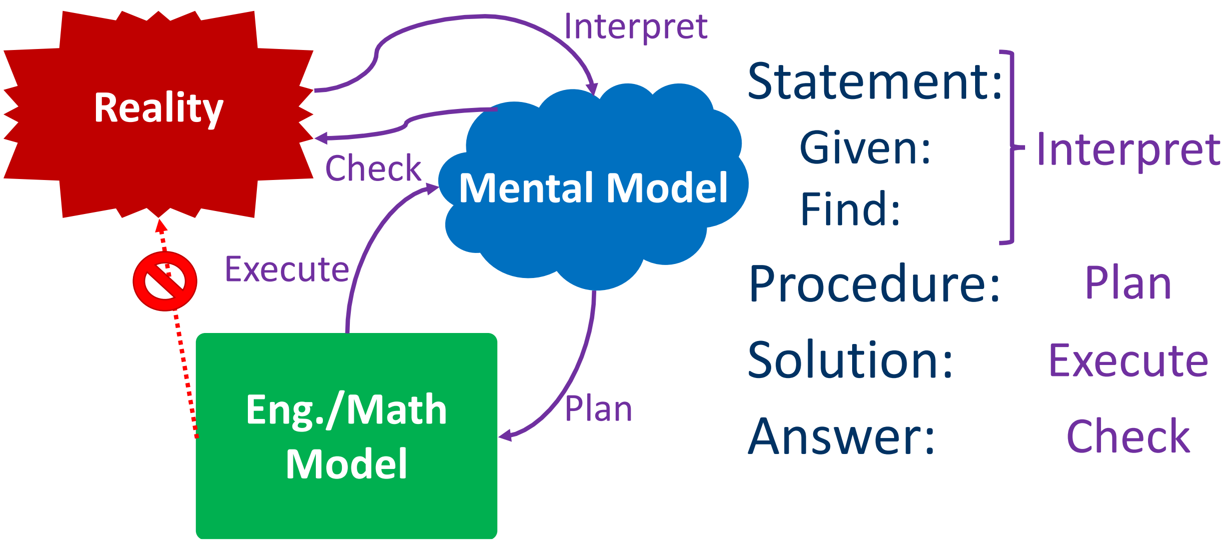

Figure 5. The relationship between the three models and engineering problem solving

Interpret

The first step to solving any engineering problem is proper interpretation. At this stage, the engineer observes reality in an attempt to build a mental model of the problem. The engineering student, approaching a homework problem, will write the problem statement, identifying what is known (*Given*) and what is required (*Find*). Moving from reality to a mental model, requires observation leading to a diagram or sketch clearly showing what properties are known and what remains to be discovered. For many students, this is the hardest step; they too often desire to jump straight to an engineering/math model while skipping the important task of building their mental model and understanding the problem. However, once the student understands the problem, the appropriate engineering/math model often becomes clear.

Plan

With a developing mental model of the problem established in the writing of the givens and finds, the engineering student can plan a quantitative solution. As engineering students write the procedure, they identify the simplifications and assumptions required to move from a strong mental model to an appropriate engineering/math model. Appropriate scientific laws, equations, and codes must flow from the mental model. Most engineering solutions involve diagrams and sketches that illustrate the behavior described by equations. Once the appropriate engineering/math models have been identified, the engineering student can move on to executing the plan.

Execute

Finally, the engineering student can begin his solutions. He draws a diagram. He writes the equations. He solves the equations. Surely now, he is doing the work of an engineer! It may be, but only if the engineering student is continually executing the work with his mental model in mind. At every step, the engineering student must ask if the outcome is what was expected. Does the math support the diagram? If not, why? Is there an error in the math or an error in the mental model? Perhaps, the engineering/math model is overly simplified for the problem. All these comparisons between the engineering/math model and the mental model must be made as the engineer executes the plan.

Check

Finally, the work completed, the engineering student is ready to record the answer. Still the models must be considered. By recording an answer, the engineering student is making a claim about the reality described by the problem. The engineer must check the work ensuring that engineering/math models, mental models, and reality all agree. This last step of checking the answer completes the engineer's goal of understanding, describing and shaping reality.

Engineering students may try to jump from an engineering/math model back to reality. Danger lies along this path. Every case of engineering application must be subjected to engineering judgement to ensure that the right scientific theories have been applied properly.

Conclusion

The three-model framework and its application to engineering problem solving is a useful tool for helping students develop as engineers. The three models can help students better understand the engineering problem solving format and make sense of the efforts of their educational experience in college. Ideally, each engineering graduate has developed an appreciation and respect for reality, and mental models that intuitively understand how the world works, and the engineering/math models to quantitatively predict outcomes consistent with both their mental model and reality.

References

[1] R. B. Landis, *Studying Engineering: A Road Map to a Rewarding Career*, 5th ed. Discovery Press, 2019.
[2] L. W. Anderson *et al.*, *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, Abridged Edition*, 1 edition. New York: Pearson, 2000.
[3] D. Sayers, *The Lost Tools of Learning*, 1 edition. Fig, 2011.
[4] C. S. Dweck, *Mindset: The New Psychology of Success*, Reprint, Updated edition. New York: Ballantine Books, 2007.
[5] J. Dunnicliff and D. U. Deere, Eds., *Judgment in Geotechnical Engineering: The Professional Legacy of Ralph B. Peck*, 1 edition. New York: Wiley-Interscience, 1984.