Physical Modeling for Engineering Education: Learning Theory Approach

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Physical Modeling: Evolving Use in Engineering Education

20th Century
(Image courtesy Ferguson, 1997)

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Physical Modeling: Evolving Use in Engineering Education
Benefits of Physical Modeling for Education: Geotechnical Perspective

- Clearly portray complex, nonlinear mechanisms and phenomena that are difficult to visualize

- By directly observing systems at the model scale, students develop an intuition and physical sense for the fundamental mechanisms that govern their behavior

- Models may be tested to collapse, thereby allowing one to witness failure mechanisms that are not seen in traditional laboratory sessions

- Students can directly assess the deviation between the predicted and actual performance of a system
Benefits of Physical Modeling for Education: Pedagogical Perspective

• When used in conjunction with traditional instruction methods such as lectures, highly kinesthetic, interactive activities can improve learning and motivate students.

• Require students to use multiple perception modes, engage in a wide array of learning activities, and participate in “active” learning exercises.

• Laboratory demonstrations can have the effect of creating a “disequilibrium” in students, requiring them to revise their understanding and inspiring more in-depth learning.
How Does One *Strategically* Incorporate Modeling into the Curriculum?

- Highly visual, kinesthetic activities such as modeling can improve student understanding of complex phenomena; however, *this alone does not ensure that comprehensive learning will occur*

- Modeling must be integrated into course modules in a way that recognizes the natural learning cycle of students.

• “Theory of experiential learning” serves as basis of learning process model

A circular or spiral model of how people learn

• Modified and extended by teaching at a variety of levels (4MAT system; McCarthy, 1987)
Why Kolb’s Learning Theory?

• Conceptually similar to other established learning theories

• Previously been applied in engineering courses

• Emphasizes a variety of learning styles and thus is appealing to a broad range of students

• Based on the “theory of experiential learning,” emphasizes the importance of concrete experiences for learning

• Systematic nature provides students with a greater awareness of their own learning process

• Comprehensive, yet relatively easy to apply to engineering instructional modules
Kolb’s Learning Model

- Experience
- Action
- Conceptualization
- Reflection

Perceiving

Processing
Kolb’s Learning Model

- Four types of learners
- While learners prefer certain modes, they are capable of operating in all four quadrants
4MAT System (McCarthy 1987)

Concrete Experience (CE)

Quadrant One

Active Experimentation (AE)

Quadrant Four

Reflective Observation (RO)

Quadrant Three

Abstract Conceptualization (AC)

perceiving

processing

Quadrant Two
4MAT System (McCarthy 1987)

Learning cycle elements (actions)

Concrete Experience (CE)

Quadrant One

Reflective Observation (RO)

Quadrant Two

Learning stage

Quadrant Three

Active Experimentation (AE)

Quadrant Four

perceiving

processing

Abstract Conceptualization (AC)
4MAT System: Learning Cycle Elements

Concrete Experience (CE)
- Actively experiencing an activity
  - Lab. session
  - Observations
  - Field trip

Reflective Observation (RO)

Active Experimentation (AE)

Abstract Conceptualization (AC)

Quadrant One

Quadrant Two

Quadrant Three

Quadrant Four

TO: teaching objectives  LE: learning experiences

Why?

Motivator
- TO: provide meaning and context
- LE: observing, listening, experimenting
4MAT System: Learning Cycle Elements

Concrete Experience (CE)

Reflective Observation (RO)

Active Experimentation (AE)

Abstract Conceptualization (AC)

Quadrant One

Quadrant Two

Quadrant Three

Quadrant Four

Consciously reflecting upon experience

• Discussion
• Journal keeping

What?

Information giver

TO: organize, integrate new material
LE: patterning, comparing
4MAT System: Learning Cycle Elements

How?
Coach/Facilitator
TO: apply subject matter
LE: practicing, doing, linking theory to application

Concrete Experience (CE)

Reflective Observation (RO)

Quadrant One

Quadrant Two

Quadrant Three

Quadrant Four

Active Experimentation (AE)

Abstract Conceptualization (AC)

Conceptualize a model or theory
- Lectures
- Reading
- Projects

perceiving
processing
4MAT System: Learning Cycle Elements

What if?

Evaluator

TO: share discoveries, evaluate performance
LE: adapting, modifying, summarizing, making new connections

Test model or theory
• Homework
• Experiments
• Analysis

Concrete Experience (CE)

Reflective Observation (RO)

Abstract Conceptualization (AC)

Quadrant Four

Quadrant One

Quadrant Two

Quadrant Three

Active Experimentation (AE)
Example Application: Bearing Capacity Theory
Example Application: Bearing Capacity Theory

**Concrete Experience (CE)**
- Lecture to introduce concept of bearing capacity
- Present photographs of shallow foundation systems
- Physical model demonstration - shallow foundation tested to failure

**Active Experimentation (AE)**
- Assignment: predict performance of a shallow foundation system
- Physical model experiment: Different shallow foundation system tested to failure

**Reflective Observation (RO)**
- Assignment: review model demonstration; record observations, make measurements and sketch the failure mechanism(s)
- Class discussion about model demonstration

**Abstract Conceptualization (AC)**
- Classroom lecture(s) on bearing capacity theory
Conclusions

• Physical modeling: powerful simulation technique

• Most effective if strategically integrated into course modules

• Simple, yet comprehensive, approach developed for this purpose

• Applicable to a wide range of subjects

• Must demonstrate the effectiveness of this approach through program assessment

• Take advantage of high quality pedagogy research
Geotechnical Physical Modeling for Education: Learning Theory Approach

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Abstract: As physical modeling sees increasing use in geotechnical engineering education, there is a need for a strategic approach for integrating this powerful simulation technique into courses in a way that ensures the greatest benefit for students. For this reason, a learning theory approach, which recognizes the natural learning cycle of students, has been developed. The approach is based on a modified version of the learning theorist David Kolb’s “theory of experiential learning.” The approach emphasizes a variety of learning styles and thus is appealing to a broad range of students. The approach is relatively easy to apply to traditional geotechnical engineering coursework and requires only a modest effort to adopt. It is expected that by using this approach when designing course modules, instructors can increase the likelihood that comprehensive learning will take place. While this paper focuses on physical modeling for geotechnical engineering, the approach presented here has educational applications to an array of other civil engineering topics.


CE Database subject headings: Engineering education; Simulation models; Centrifuge model; Geotechnical engineering.

Introduction

Physical models have served important functions in engineering research, practice, and education for hundreds of years (Ferguson 1992). In geotechnical engineering, the first reduced scale physical models were used primarily for research, and usually in a lab environment. A key limitation to many of these studies was that the stress condition behavior of soil was not properly accounted for in a lab environment, thereby making it difficult for quantitative interpretations of the experimental data to be made.

The advent of modern geotechnical centrifuge modeling in the late 1980s addressed this limitation and greatly increased the acceptance and use of physical modeling for geotechnical engineering research. Physical modeling, especially in high gravity centrifuge environments, has evolved rapidly over the past several decades. Today, there are well established and validated laws of similarity to relate the behavior of reduced scale models to prototype earth systems (e.g., Santamarina and Goodings 1989, Liu 1989; Schotfried and Steedman 1988; Calligan et al. 1996). Moreover, advances in system control, rendering, and experimental design have significantly improved the performance of test systems while minimizing the effects of instrumentation and boundary conditions on model response. Reviews of contemporary physical modeling practice have been presented by Paulia et al. (1993), Kutter (1995), Wood et al. (2002), and Garnier (2002), among others.

While physical modeling remains a tool for research, increasingly it is being used in both geotechnical engineering practice and education. For example, Becker et al. (1998) discuss how physical modeling was used to help design the foundation of the Confederation Bridge and Yang et al. (2004) highlights the role of centrifuge modeling for the seismic retrofit design of the George Masury Tunnel. Other recent practice-related applications of physical modeling are presented by Anderson et al. (2003) and Teshii et al. (2004). As an educational tool, physical modeling is now being used at universities worldwide to teach fundamental yet complex concepts of soil mechanics such as bearing capacity, lateral earth pressure, slope stability, and flow through porous media (e.g., Craig 1989; Mitchell 1998; and Dewoolkar et al. 2003). Moreover, the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program, a recent modeling initiative in the United States, includes a significant educational component (Anagnos and Fatta 2004) that is expected to further promote the use of modeling in education.

As the use of physical modeling in geotechnical engineering education grows, it is important to identify a strategic approach for introducing this simulation technique into courses in a way that ensures the greatest benefit for students. While it has long been recognized that students can improve their understanding of complex mechanisms and phenomena by engaging in highly visual, kinesthetic activities such as physical modeling, this alone does not ensure that comprehensive learning will occur (Wartman 2001). To maximize its educational benefits, physical modeling must be integrated into geotechnical engineering instructional modules in a manner that recognizes the natural learning cycle of students.

This paper reviews educational applications of physical modeling and presents a comprehensive but straightforward learning theory based approach for integrating model demonstrations and experiments into geotechnical engineering instructional modules. There is convincing evidence that a student’s understanding and retention of fundamental concepts will be enhanced if physical modeling is strategically integrated into coursework. Although this paper focuses on physical modeling for geotechnical engi-
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