BEST PRACTICES IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) IN CAMBODIAN HIGHER EDUCATION INSTITUTIONS

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Summary of today’s agenda

- Tuesday, 15 October
  - Debunking myths about learning
  - Instructional design
  - Encouraging innovation in STEM
DEBUNKING MYTHS ABOUT LEARNING
What is the impact of poor instruction?

- **Negative gains**
  - Poor instruction can disrupt prior knowledge

- **Negative transfer**
  - Poor instruction can hinder future learning
MYTH: CATERING TO "LEARNING Styles" IMPROVES EFFECTIVENESS
MYTH: Catering to “learning styles” improves effectiveness

- Learning styles
  - Visual / Auditory / Kinesthetic...

- Cognitive styles
  - Field dependent / Field independent

- No well-designed study has found any evidence supporting a relationship between “styles” and learning outcomes
  - (Duff & Duffy, 2002; Henson & Hwang, 2002; Kavale & Forness, 1987; Loo, 1997; Richardson, 2000; Stahl, 1999)
Styles vs. Preferences vs. Strategies

- Learning Style
  - “I learn (best) in this way.”

- Learning Preference
  - “I prefer learning in this way.”

- Learning Strategy
  - “I take notes on the readings, practice, etc.”

- Preference ≠ Style ≠ Strategy
MYTH: INTELLIGENCE DETERMINES LEARNER SUCCESS
Intelligence (fluid ability) measures the ability to solve a problem for which an individual lacks knowledge (Gustafsson, 1988; Horn & Cattell, 1967)
- Pattern recognition, logic problems, etc.

Prior knowledge is:
- Available before learning a certain task
- Structured and interconnected
- Declarative (knowing what) and procedural (knowing how)
- Partly explicit and partly tacit
- Dynamic in nature and stored in the knowledge base (Dochy, 1994)
Intelligence, Knowledge, and Achievement

- Achievement is determined by:
  - The knowledge a student has available
  - The intelligence a student applies to fill in knowledge gaps
  - The motivation a student has to do each as appropriate

- Expertise has no correlation with intelligence (Ceci & Liker, 1986; Doll & Mayr, 1987; Ericsson & Lehmann, 1996; Hulin, Henry, & Noon, 1990; Masunaga & Horn, 2001)
The Effects of Instruction

- Bloom’s (1984) Two-Sigma Problem

  - Comparison of student achievement under conventional classroom teaching, learner-centered (mastery) classroom teaching, and tutoring
    - Tutored students performed 2 standard deviations above the conventional classroom mean
      - 50th percentile in tutoring = 98th percentile in conventional
    - Tutored students had less variation in performance
      - 90% of scores fell into the same range as the top 20% of conventional

  - Correlations between intelligence and achievement
    - Conventional: $r = 0.60$ (36% of variance)
    - Tutoring: $r = 0.25$ (6.25% of variance)
What was Different?

- Learner-centered classroom teaching* and tutoring provided:
  - Extensive explanations
  - Individualized feedback to correct knowledge errors and gaps
- Students were not forced to infer necessary knowledge to perform assessment tasks

*1.7 SD advantage over conventional
MYTH: LEARNER CHOICE AND UNGUIDED DISCOVERY ENHANCE LEARNING
Experiential Learning

- Discovery Learning
  - Expected that students induce (“discover”) all elements of solution
  - No support

- Problem-based Learning
  - Not universally defined
  - Requires that students practice authentic problem-solving skills
  - Variable support

- Guided Experiential Learning
  - All skills and knowledge are identified at start and taught if needed
  - Students asked to apply that knowledge to authentic problems
Data from decades of studies of discovery learning and unguided problem-based learning indicate:

- Achievement is poor when students are not provided with the information necessary to guide informed problem-solving decisions
  - (Kirschner, Sweller, & Clark, 2006; Mayer, 2004)

- Students are likely to become overwhelmed, confused, and lose motivation to pursue learning goals
  - (Chandler & Sweller, 1991; de Jong & van Joolingen, 1998; Goodyear, et al., 1991; Kalyuga et al., 2003; Lewis et al., 1993)

- Students who do succeed in discovery learning tasks do not demonstrate any advantage on later tasks compared to those who received explicit instruction (Klahr & Nigam, 2004)
Instruction and Intelligence

- When students reason inductively, the intelligence-performance relationship is robust (Veenman, 1993; Veenman & Elshout, 1995)
- When explanations are provided as needed, student performance becomes less correlated with intelligence
MYTH: DIGITAL MEDIA IMPROVE LEARNING
Attributes of Media and Multimedia

Media such as video, computers, multimedia and teachers are “vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition.” (Clark, 1983, p. 249)
Learning from Multimedia

- Meta-analyses comparing the results of hundreds of studies find no difference between computer-based and other forms of instruction
  - (Bernard, et al., 2005; Clark, 2001)

- Most individual studies that report differences do not control for other differences between conditions:
  - Ability of students
  - Information available
  - Time allotted
Technological Affordances

- Certain media have properties that allow for more efficient transfer of certain types of information
  - Visual maps
  - Auditory music
  - Tactile textures
- Importance of efficiency increases as level of prior knowledge decreases
Examples

- Live lecture vs. video lecture
- Physical manipulatives vs. virtual manipulatives
  - “Point and Click or Grab and Heft: Comparing the Influence of Physical and Virtual Instructional Materials on Elementary School Students' Ability to Design Experiments” (Triona & Klahr, 2003)
- Learner choice of media (video or text) vs. learning outcomes
  - Television is “easy” and print is “tough”: The differential investment of mental effort in learning as a function of perceptions and attributions (Salomon, 1984)
Popular Features of Multimedia

- **User control of instruction**
  - **Help tools**
    - Learners who opt to use help resources are typically most advanced, not most in need of help (de Jong & van Joolingen, 1998)
  - **Sequencing**
    - Students who sequence material for themselves frequently skip necessary foundational knowledge, examples, and practice opportunities that facilitate learning (Ross & Rakow, 1981; Niemiec, Sikorski & Wallberg, 1996; Merrill, 2006)
  - **Pacing**
    - Learner control of pacing is beneficial to learning, because students can ensure mastery of the material before moving on to subsequent topics (Mayer & Chandler, 2001)
Popular Features of Multimedia

- Games
  - Motivation
    - Winning strategies are not always those that foster learning (Wolfe, 1997)
    - Issue of game design vs. instructional design (Garris et al., 2002)
  - Problem-solving in game contexts often requires discovery of an effective strategy
    - Unguided discovery learning ineffective for all but the most advanced learners (Kirschner, Sweller, & Clark, 2006)
What implications do these myths have in relation to the learner-centered pedagogical techniques discussed yesterday:

- Think-pair-share
- Project-based learning
- Clickers
- Learner assessments (1 minute paper, just-in-time teaching)
Two Components

- What content is taught
- How to structure and deliver content
Instructional Design Considerations

- Completeness and accuracy of instruction improve student performance

- Misconceptions are robust and impair future learning and performance
Expertise and the Process of Education

Content Expertise

Curriculum → Pedagogy → Assessment → Outcome

Pedagogical/Instructional Design Expertise
Dependence on Experts’ Explanations in STEM Education

- Experts identify key instruction content and assessment tasks
- Experts provide explanations of optimal performances and supporting knowledge
  - Lectures, demonstrations, textbooks, manuals, apprenticeships

Questions
- Are those explanations accurate?
- What tools facilitate elicitation of best information?
- What are the implications for instructional quality and process?
Instructional Limitations of Expertise (Feldon, 2007)

- **Strengths**
  - Highly accurate recall of events (what)
  - Extensive experiences and conceptual knowledge
  - Superior performance

- **Weaknesses**
  - Inaccurate recall of procedures (how)
  - Rigid mental models
  - Poor abilities to predict learners’ performance and instructional needs
Robust mental models/schemas may be too inflexible for accurate recall

Retrospective self-reports may be corrupted by errors of generalizability and rationalization due to a priori causal theories (Nisbett & Wilson, 1977; Wegner, 2002)

Intermediate effect (Allen & Casbergue, 1997; Rikers et al., 2000)
Expertise and Self-Report

Intermediate Effect
(Rikers et al. 2000)

Accuracy of Recall

Expertise
Examples from Scientific Practice

- Expert physicists’ predictions of object trajectories differ significantly from those generated from implementations of their self-reported reasoning processes (Cooke & Breedin, 1994)

- Scientists in lab meetings where new conclusions and discoveries made could not accurately recall the reasoning processes by which they were achieved (Dunbar, 1997, 2000)
Self-Report in Instruction

- Plausible fictions used to explain complex or unconscious processes (Johnson, 1983)
- Tendency to omit decision alternatives and criteria (Maupin, 2003; Velmahos et al., 2004)
Impacts on Learner Outcomes

- Decision errors distort training
  - Decisions cannot be observed and so cause gaps in learning
  - Gaps must be filled by trial and error
Current Instruction of Research Skills

- Current training in research skills based on self-reports of expert researchers (Golde & Dore, 2001)
  - Course lectures and textbooks
    - “Armchair” reflections of researchers (Schunn & Anderson, 2001, p. 87)
  - Mentorship through modeling / cognitive apprenticeship
    - “…where an expert carries out a task, possibly verbalising [sic] their thought processes, so the student can observe and build a conceptual model of the process required to complete the task” (Pearson & Brew, 2002, p. 140)
    - Student success in these circumstances is dependent on accurate, comprehensible explanations of strategies by the mentor and opportunities for active participation in the problem-solving process (Radziszewska & Rogoff, 1988, 1991)
Technique for Improving Validity of Experts’ Self-Reports

- Cognitive Task Analysis
  - Protocol-based analysis of effective skill
  - Case-based reasoning
  - Semi-structured interviews
    - Multiple experts
  - Convergence around expert strategy
    - Criteria for instructional use:
      - Procedure will be effective
      - No missing steps
      - No unnecessary steps included
Cognitive Task Analysis (CTA)

Extends traditional task analysis to capture information about both the *overt observable behavior* and the *covert cognitive functions* behind it to form an integrated whole.

Schraagen, Chipman & Shalin, 2000
Example of CTA: Experimental Design

1. Identify and list in lab notebook which factors from the literature, personal knowledge of relevant biological system(s), and conditions surrounding observation that led to the research question are likely to influence obtained measurements of dependent variable stated in hypothesis.

2. IF listed factor is not independent variable in hypothesis THEN:
   a. IF elimination of factor will not disrupt biological system or threaten organism health/survival THEN list in lab notebook as factor to be eliminated.
   b. IF elimination of factor will disrupt biological system or threaten organism health/survival THEN list in lab notebook as factor to be held constant at level recommended in literature or observed in environment as satisfactory for maintenance of biological system or health/survival of organism.
   c. IF factor cannot be controlled or eliminated to prevent influence on dependent variable THEN identify and list in lab notebook the locations or other environmental conditions that will ensure equivalent impact on all experimental conditions.
   d. IF no locations or environmental conditions exist where equivalent impact of factor on measurement of dependent variable can be identified THEN identify appropriate measure of factor from literature and include measurement of factor in protocol for reference during data analysis.
What Evidence for Effectiveness?

Typically 30-50% learning gains with CTA-based instruction

- Patent examiners finish 75% faster (6 mo. Vs. 2 yrs.)
  - Production increase 200%+ mistakes down 65%
- Surgical residents finish 25% faster, learn 40% more
  - Important mistakes reduced 50%
- Tofel-Grehl & Feldon (2013) 57 comparisons averaged 30% learning increase over control
  - Using Hedges’ g (0.88) for conservative estimate
Extended CTA-based Instruction

- Improving STEM Retention through Instruction: Leveraging Faculty Expertise
  (Feldon, Stowe, & Showman, 2007-2010)
  - NSF Science Technology Engineering and Mathematics Talent Expansion Program
  - Longitudinal, double-blind study of CTA-based instruction for biology majors
# CTA-based vs. Traditional Instruction Biology 101 Lab Reports

*Feldon et al. (2010); Feldon & Stowe (2009)*

<table>
<thead>
<tr>
<th>Universal Lab Report Rubric Criteria</th>
<th>Treatment Mean (SD)</th>
<th>Control Mean (SD)</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discussion: Conclusions based on data</strong>&lt;br&gt;Conclusion is clearly and logically drawn from data provided. A logical chain of reasoning from hypothesis to data to conclusions is clearly and persuasively explained.</td>
<td>0.90 (.50)</td>
<td>0.77 (0.48)</td>
<td>4.378</td>
<td>.037*</td>
</tr>
<tr>
<td><strong>Discussion: Alternative explanations</strong>&lt;br&gt;Alternative explanations are considered and clearly eliminated by data in a persuasive discussion.</td>
<td>0.43 (0.52)</td>
<td>0.28 (0.44)</td>
<td>6.171</td>
<td>.014*</td>
</tr>
<tr>
<td><strong>Discussion: Limitations of design</strong>&lt;br&gt;Limitations of the data and/or experimental design and corresponding implications discussed.</td>
<td>0.70 (0.63)</td>
<td>0.54 (0.57)</td>
<td>4.703</td>
<td>.031*</td>
</tr>
<tr>
<td><strong>Discussion: Implications of research</strong>&lt;br&gt;Paper gives a clear indication of the implications and direction of the research in the future.</td>
<td>0.31 (0.46)</td>
<td>0.21 (0.40)</td>
<td>3.463</td>
<td>.064</td>
</tr>
<tr>
<td><strong>Discussion: Total Score</strong></td>
<td>2.34 (1.49)</td>
<td>1.78 (1.37)</td>
<td>9.501</td>
<td>.002**</td>
</tr>
</tbody>
</table>
Biology 101 Attrition (Withdraw Rates)

<table>
<thead>
<tr>
<th></th>
<th>CTA Condition</th>
<th>Control Condition</th>
<th>Fisher’s Exact (2-sided)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-week Enrollment</td>
<td>142</td>
<td>172</td>
<td>-</td>
</tr>
<tr>
<td>Final Enrollment</td>
<td>140</td>
<td>158</td>
<td>-</td>
</tr>
<tr>
<td>Overall Dropouts</td>
<td>2</td>
<td>14</td>
<td>( p = .005^{**} )</td>
</tr>
<tr>
<td>Biology Majors</td>
<td>1</td>
<td>3</td>
<td>( p = .334 )</td>
</tr>
<tr>
<td>Non-Majors</td>
<td>1</td>
<td>11</td>
<td>( p = .010^{**} )</td>
</tr>
<tr>
<td>Women</td>
<td>1</td>
<td>8</td>
<td>( p = .041^* )</td>
</tr>
<tr>
<td>Men</td>
<td>1</td>
<td>6</td>
<td>( p = .072 )</td>
</tr>
</tbody>
</table>
INSTRUCTIONAL DESIGN BASED ON HUMAN COGNITIVE ARCHITECTURE
An Experiment...

- Remember the numbers in the order I recite them.
- Please take no notes.
Let’s Try One More...
Attention and Memory

- **Short term memory**
  - Conscious awareness
  - Very limited capacity (4 +/- 1 chunks)
  - Very limited duration (~30 seconds)
  - Analogous to computer RAM
Using the Space Well

- Organized knowledge takes up less space

- As skills are practiced, they take up less space
  - Habits are unconscious
What Kinds of Things Waste Space?

- Redundant or irrelevant information
- Background noise or activities
- Anxiety
What Happens When you Exceed the Limits?

When too much information needs to be processed:

- People miss details
  - No space available to notice
- People revert to old habits
  - “Smaller” elements are substituted for “larger” elements unintentionally
  - Procedures and goals can change
A Metaphor

- A bucket has a limited volume that it can hold.
- When choosing how to fill it, you can put in a few large objects or more smaller objects.
- Newer concepts and skills are large objects.
- Other information and distractions take up space in the bucket.
- Based on performance needs, choose carefully which objects should go in the bucket to ensure that all necessary items can fit.
What Does This Mean for Training?

- Present new information in order from simplest (smallest) to most complex (larger).

- Do not present information that is unnecessary, optional, or irrelevant to the desired performance.

- Provide many opportunities for practice during training to reduce the “size” of new skills prior to use in the field.
Traditional Part-Whole Task

Now do:
Traditional Part-Whole Task

Now do:
Deepening Complexity
INTEGRATION OF CONTENT AND INSTRUCTIONAL DESIGN
## Knowledge Types in CTA for Design

<table>
<thead>
<tr>
<th>Knowledge Type</th>
<th>Presentation</th>
<th>Practice/Assessment</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td>List of steps, demonstration, problem that procedure will solve</td>
<td>Recognize, recall, or reorder the steps</td>
<td>Decide when to use; perform action and decision steps;</td>
</tr>
<tr>
<td>Concept</td>
<td>The definition, critical attributes, examples, non-examples</td>
<td>Recognize, recall, or explain the definition or attributes</td>
<td>Identify, classify, or create examples</td>
</tr>
<tr>
<td>Process/System</td>
<td>Describe how something works in stages with transitions, diagrams, inputs, outputs, stories</td>
<td>Recognize, recall, explain, or reorder the stages</td>
<td>Identify origins of problems; troubleshoot to solve problems in the process</td>
</tr>
<tr>
<td>Principle</td>
<td>Describe cause and effect principle with examples, analogies, problems it solves.</td>
<td>Recognize, recall, or explain the principle</td>
<td>Decide if principle applies; predict an event; apply the principle to solve a problem or make decisions</td>
</tr>
</tbody>
</table>

Instructional Design to Foster Innovation
(Feldon, Hurst, Rates, & Elliott, 2013)

- Authentic problem solving and inquiry
  - Science and engineering require integrated process and content (dual problem space)
  - Explicit instruction of procedures that include decision points
  - Avoid “cookbook” labs
  - Reward novel solutions while maintaining rigor
- Varied practice and contexts for problems
  - Incremental increases in complexity and degrees of freedom
- Provide specific feedback and opportunities for reflection
  - Strengths and weaknesses of design/analysis
  - Explicit group review; “post mortem”
Activity:

- Take one of the examples generated from yesterday’s think-pair-share and revised it based on instructional design principles
REVIEW AND OVERVIEW
DAY 2

✓ Debunking myths about learning

✓ Instructional design
Homework for tomorrow

- Re-familiarize yourself with the following aspects of a course that you teach:

  - Reading list
  - Assignments and tests
  - In-class activities (e.g., labs)