

Cognitive Load Theory & Universal Design Principles: Applications to Test Item Development

Stephen N. Elliott

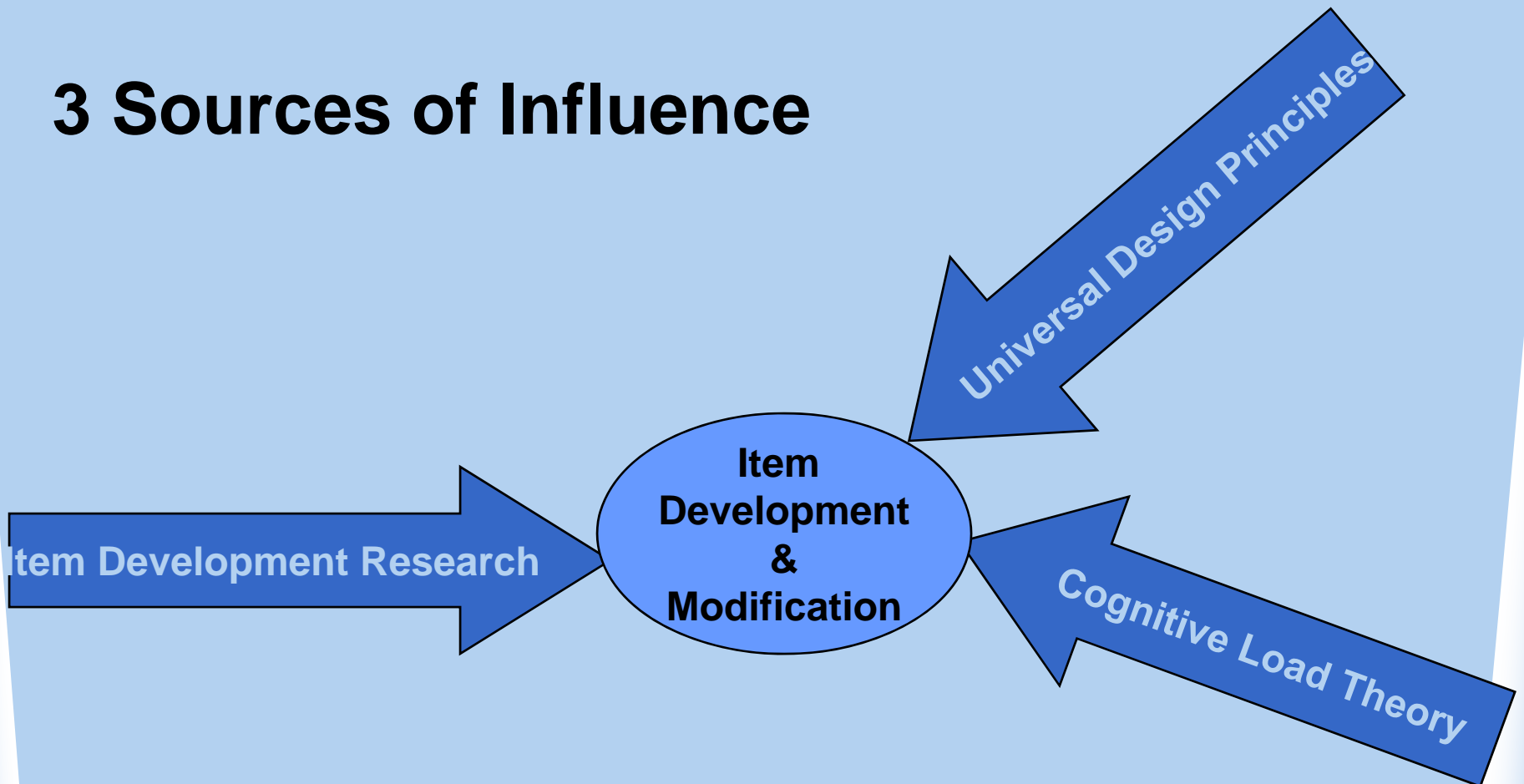
with

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Theory & Research Driven Item Design

3 Sources of Influence



Goals of Modification

- **Increase access for all test takers;**
- **Remove extraneous material;**
- **Maintain the same depth of knowledge;**
- **Improve efficiency;**
- **Increase validity of inferences from test results.**

Accessibility:

Definition & Background

- *The extent to which an environment, system, or product eliminates barriers and permits equal access to all components and services for all individuals.*
- Background – **Universal Design Principles**
 - ◆ The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.

Facilitating Access & Reducing Irrelevant Variance

- **Testing Accommodations** - changes to the way a test is administered or responded to by a student. Such changes are often categorized as changes to the setting, timing, scheduling, presentation, and method of responding.
 - ◆ To facilitate participation from individuals who have not taken tests in the past.
 - ◆ To offset distortions in test scores caused by a disability without invalidating the test results (i.e., increase validity of score).
- **Testing Modifications** – Changes to test items to facilitate access, remove extraneous material to facilitate processing, and improve meaningful responding and thus results.

Universal Design Principles

- **Principles of Universal Design** are intended to maintain equity among user groups while providing the same or equivalent means of use for all users;
 - ◆ **Eliminate unnecessary complexity;**
 - ◆ **Arrange information consistent with its importance;**
 - ◆ **Use prompting and feedback during and after task completion;**
 - ◆ **Present information redundantly (visual, verbal, tactile);**
 - ◆ **Maximize legibility and construct;**
 - ◆ **Simplify directions and instructions;**
 - ◆ **Reduce the potential for error.**

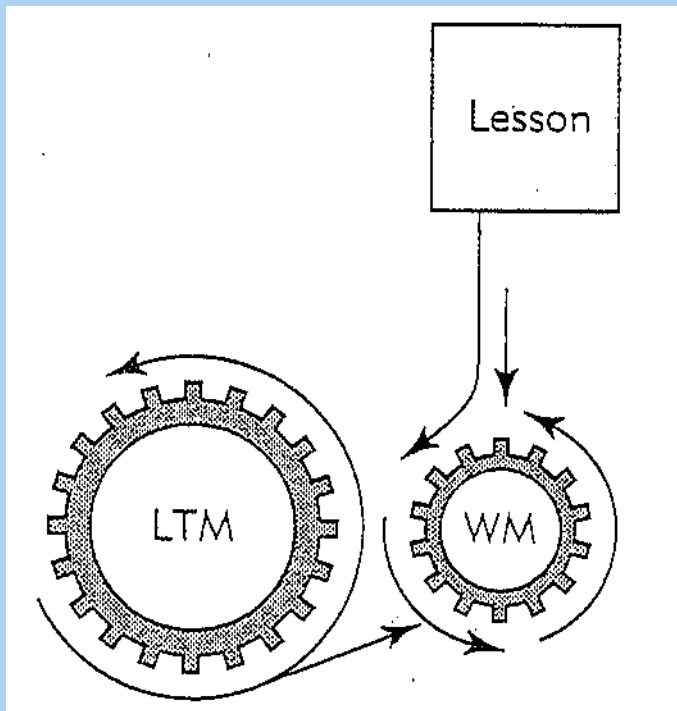
Cognitive Load Theory: Origins

- CLT gives a framework for studying cognitive processes and instructional design
- Started in 1980s and developed and expanded throughout the 1990s
- Considers intrinsic properties of material to be learned, how information is presented, and how people process information
 - ◆ Universal learning principles that can lead to efficient instructional environments

Learning Process

- **Working Memory (WM)**
 - ◆ Conscious cognitive processing
 - ◆ Can only handle a limited amount of information (no more than 2-3 novel interacting elements)
- **Long-Term Memory (LTM)**
 - ◆ Stores our schemas
 - Schemas combine multiple pieces of information into a single element with a specific function
 - Schemas can go from long-term memory to the working memory when needed
 - Load on working memory is reduced as schemas become automatized

Working and Long-Term Memory



- WM is the primary site for conscious processing
- WM has a limited storage capacity
- LTM has a large storage capacity and is the primary site for storing schemas
- Schemas can be pulled from LTM to assist with processing in WM

Learning & Test Taking Processes

- The following processes work together to help a learner achieve his/her learning goals
 - Attention
 - Activation of prior knowledge
 - Elaboration-rehearsal
 - Encoding and retrieval
- These processes rely on the working memory
 - ♦ If the working memory has to use additional effort unrelated to these processes, the learning becomes inefficient and takes longer

Information to be Learned

- Structure of information learners need to understand varies and impacts how efficiently and effectively one learns
- According to CLT
 - ◆ Information can have low to high element interactivity
 - ◆ Element interactivity --> intrinsic cognitive load
 - The level of demand placed on the working memory to learn the new information is based on intrinsic properties of the material
 - Instructional strategies cannot change intrinsic cognitive load

3 Key Assumptions about How People Learn

- **Active Processing assumption** – knowledge construction requires attention, organizing materials into meaningful structures, using prior knowledge to comprehend information.
- **Dual Channel assumption** – cognitive processing of information occurs into 2 separate channels (auditory/verbal and visual/pictorial).
- **Limited Capacity assumption** – channels for processing information have capacity of approximately 7 ± 2 chunks of information; these limitations are generally associated with working memory.

3 Categories of Cognitive Load

1. Intrinsic Cognitive Load

- Amount of cognitive processing required to comprehend material

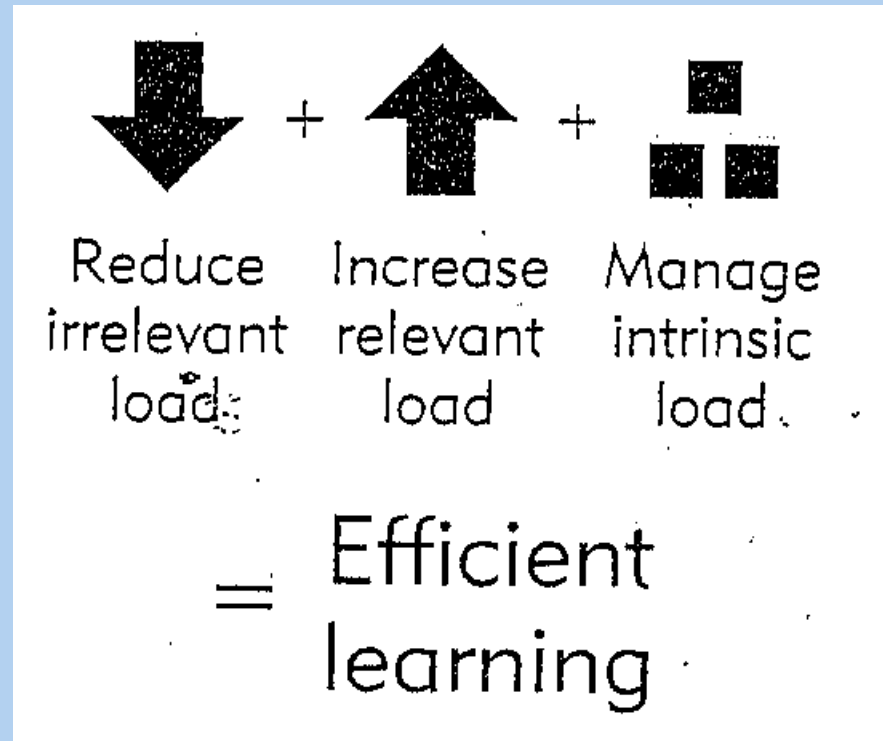
2. Extraneous/Ineffective Cognitive Load

- Unnecessary load that interferes with schema automation
- Many instructional procedures produce extraneous cognitive load for the learner

3. Germane/Effective/Relevant Cognitive Load

- Influenced by instructional strategies
- Enhances learning
- Devote working memory resources to schema acquisition and automation

Cognitive Load and Efficient Learning



Promoting Efficient Learning & Test Taking

- **Reduce extraneous load**
 - ◆ Reduce instructional content & activities that are irrelevant to the learning goal.
- **Increase germane load**
 - ◆ Increase instructional content & activities that benefit the learning goal.
- **Manage intrinsic load**
 - ◆ Break down complex tasks into a series of prerequisite tasks and supporting knowledge.

Changes in Cognitive Load

- **Cognitive load is dependent on:**
 - ◆ Learning goal and informational content
 - ◆ Learner's prior knowledge
 - ◆ Instructional environment
- Changes in cognitive load occur as a learner gains expertise
- Instructional techniques that are effective for novices are not effective for experts
 - ◆ Expertise Reversal Effect: learning environments designed for novices can depress learning outcomes of experts

Efficient Learning and Test Taking

- In review:
 - ◆ Efficient learning environments balance intrinsic, germane, and extraneous sources of load.
 - Adjust content according to:
 - **(a) expertise of the learner**
 - **(b) complexity of the content**
 - **(c) the instructional methods used in the training environment.**

Efficient Learning or Testing

- Efficient learning environments balance intrinsic, germane, and extraneous sources of load.
 - ◆ Adjust content according to (a) expertise of the learner, (b) complexity of the content, and (c) the instructional methods used in the training environment.
- Universal instructional principles derived from experimental research based on the human cognitive architecture.
- Efficiency defined along two dimensions:
 - ◆ Learner performance
 - ◆ Learner mental effort
- Efficiency (E) = Performance (P) – Mental Load (ML)
 - ◆ $E = P - ML$

Key CLT Guidelines

Source

Efficiency in Learning

(Clark, Nguyen, & Sweller, 2006)

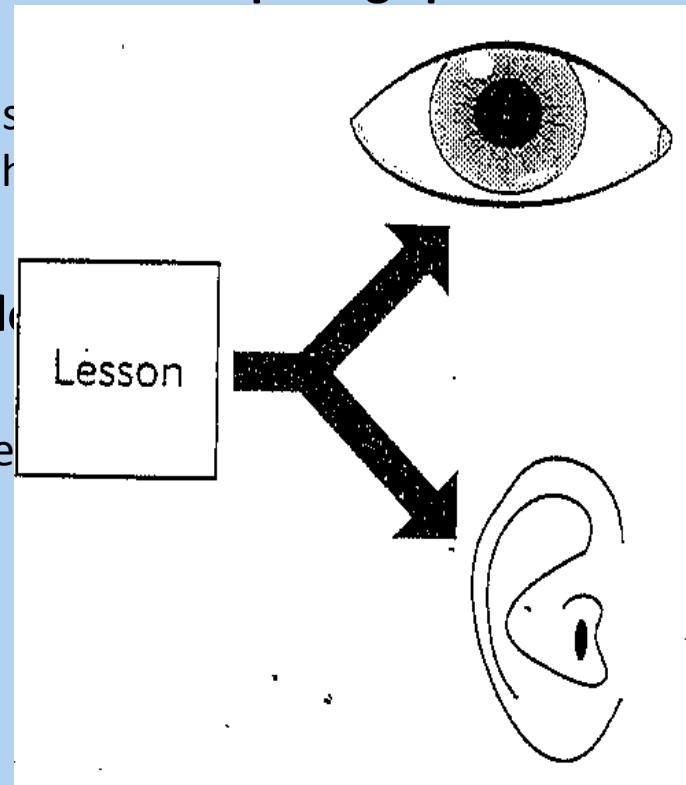
Use Visuals and Audio Narration to Exploit Working Memory Resources

1. Use diagrams to optimize performance on tasks requiring spatial manipulations.

- Diagrams permit faster processing because they are processed simultaneously (as opposed to text, which is processed sequentially).

2. Use diagrams to promote learning of rule relationships.

- Spatial relations can be readily ascertained from diagrams, whereas lengthy text descriptions are often required to describe the same relations.



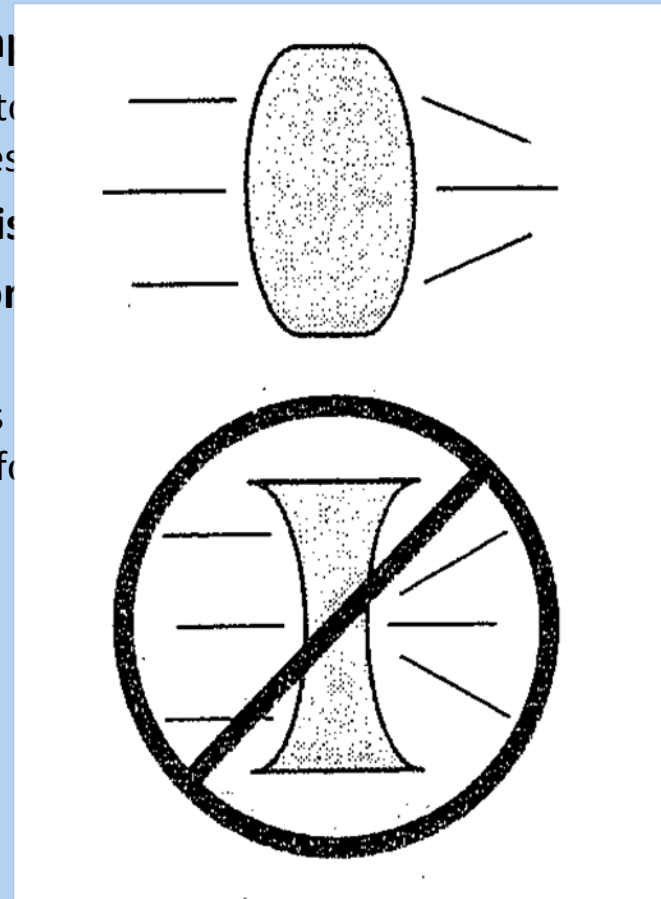
Use Visuals and Audio Narration to Exploit Working Memory Resources

- 3. Use diagrams to help learners build deeper understanding.**
 - Allow for dual encoding (by providing learners multiple opportunities to encode information).

- 4. Explain diagrams with words presented in audio narration.**
 - For complex content, visuals or text should be supported by audio narration to utilize the modality effect.

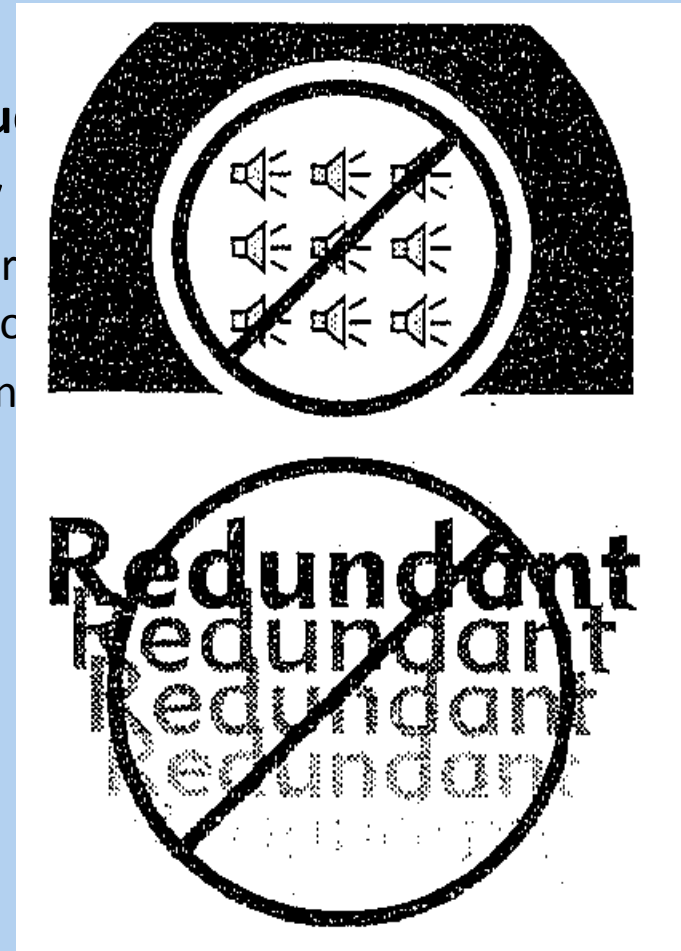
Focus Attention and Avoid Split Attention

5. **Use cues and signals to focus attention to important content.**
 - For complex content, focus learner's attention to key elements with cues and signals (e.g., bolding, highlighting, arrows, circles)
6. **Integrate explanatory text close to related visual content.**
7. **Integrate words and visuals used to teach complex concepts into the same delivery medium.**
 - Prevents *split-attention*; a source of extraneous information that requires the learner to integrate two or more dependent sources of information.



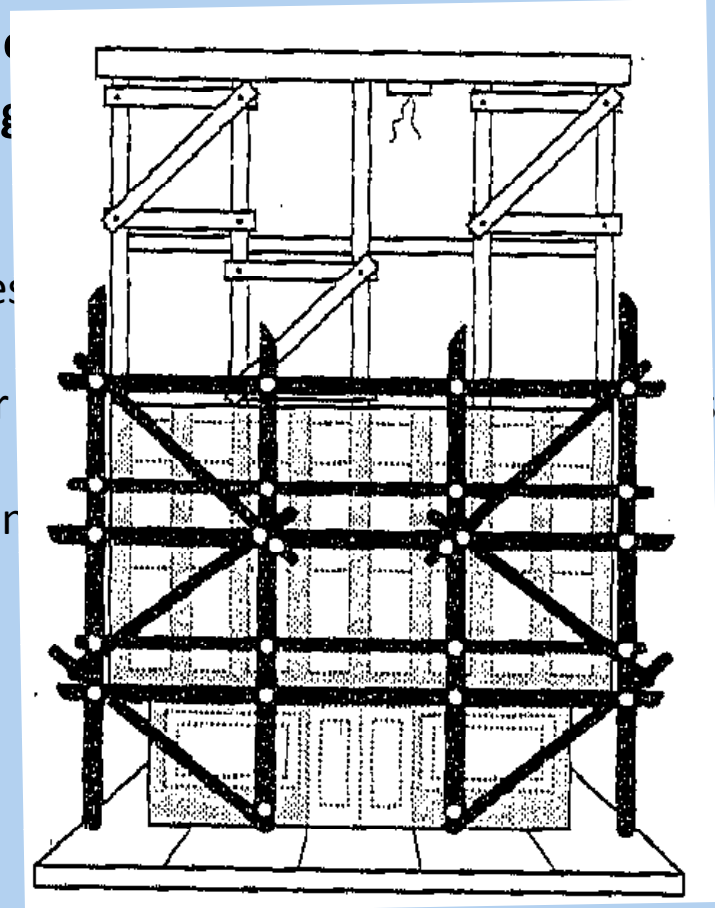
“Weed” Content to Manage Limited Working Memory Capacity

8. Pare content down to essentials.
9. Eliminate extraneous visuals, text, and audio.
10. Eliminate redundancy in content delivery
 - Minimize cognitive load by presenting your content by omitting words, visuals, or audio that do not add value.
 - Avoid increasing cognitive load by delivering content in multiple modalities (e.g., text narrated by audio).



Provide External Memory Support to Reduce Working Memory Load

11. Provide performance aids as external memory
12. Design performance aids by applying cognitive techniques.
 - Performance aids (e.g., procedure guides) should be designed for easy completion in a format that is readily accessible in the learning environment.
 - Use visuals as the predominant display format to reduce working memory and split-attention.
 - If applicable, fade memory support as training progresses.



Use Segmenting, Sequencing, and Learner Pacing to Gradually Impose Content

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16



- 13. Teach system components before teaching the full process.**
- 14. Teach supporting knowledge separate from teaching procedure**
 - Manage intrinsic load through segmenting and sequencing your content.
 - Focus on minimizing the amount of new content being processed in working memory at one time.

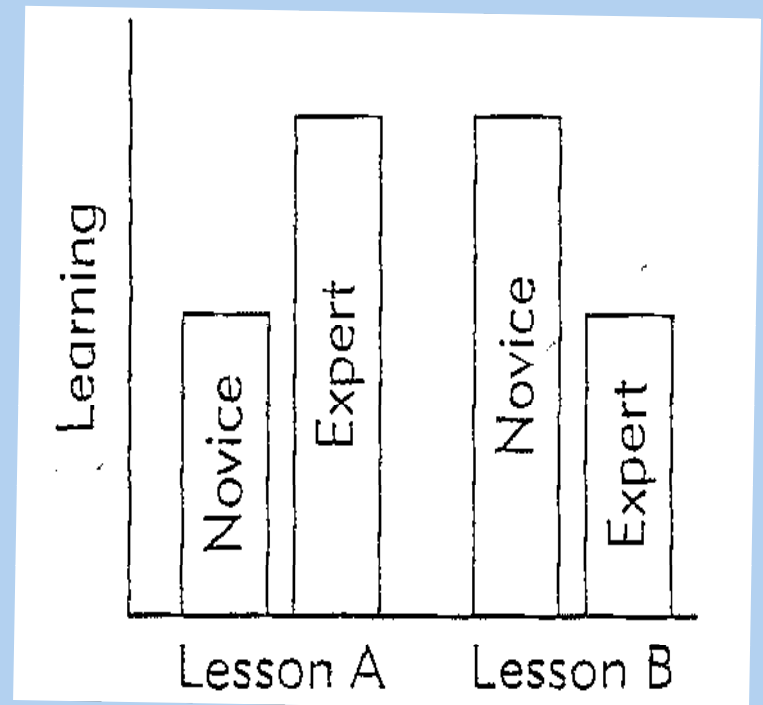
Accommodate Differences in Learner Expertise

27. Eliminate redundant content for more experienced learners.

- Experienced learners do not benefit from the combination of text and audio. If the text is self-explanatory, keep it rather than producing diagrams.

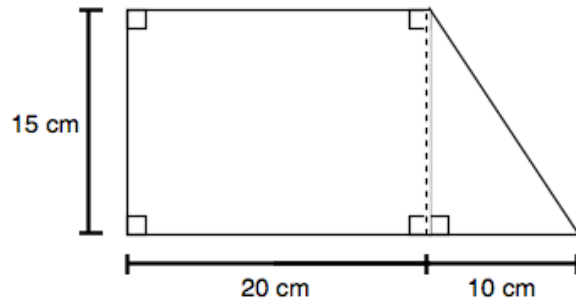
28. Transition from worked examples to problem assignments as learners gain expertise.

- Once learners have formed their own schemas for performing a task, they are better off solving problems based on those schemas.



Application to Testing

Original

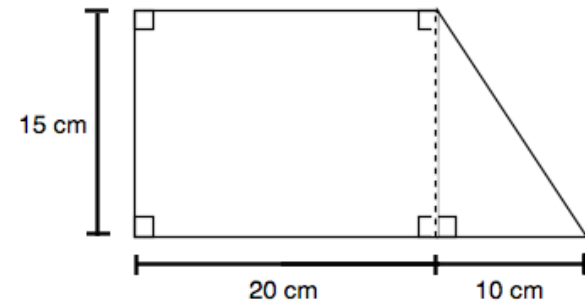


Reminder: Formulas for plane figures are available on the test reference sheet on the back of this booklet.

3. The figure above consists of one rectangle that is adjacent to one triangle. What is its area?

- A. 375 cm^2
- B. 450 cm^2
- C. 83.03 cm^2
- D. 600 cm^2

Modified



Area of a rectangle: $A = l \times w$

Area of a triangle: $A = \frac{b \times h}{2}$

3 What is the area of the figure?

- A. 375 cm^2
- B. 450 cm^2
- C. 600 cm^2

Another Example Set of Items

Original

No Swimming Today



My Uncle Reginald approached me with a furtive smile on his face. He had arrived in his pickup truck. It was old and rusty, similar to the one my father and I used to haul wood from the mill on Old Post Road.

It had been a few years since Uncle Reginald had returned from a long deployment to a country I had never heard of before, and spending time with him was always a pleasurable experience. He rarely discussed his experiences in battle or the hardships of life in the barracks, but he loved to talk about the funny things that happened on the few weekends he was able to spend in the city with his friends. I could listen to his stories all day long.

"Hi Uncle Reggie!" I called out as I ran from the front porch where I had been shucking some corn for Mama. "Are we going to Saunter Creek today to catch crawdads?"

He shook his head and motioned to the side of the barn. He had unloaded a gargantuan stack of wooden posts, two shovels, a sledgehammer, and what looked like enough wire to wrap around all the fields in Barro County.

"We're finally going to build that new corral," he said.

I knew I was in for an arduous day.

7. Based on the passage, what would be the most precise definition of the word *arduous*?

- A. building
- B. relaxing
- C. tiring
- D. easy

Modified

No Swimming Today

Uncle Reggie approached me, smiling. He had arrived in his pickup truck.

"Hi Uncle Reggie!" I called out. "Are we going swimming today?"

"No," he said, pointing to the side of the barn. I turned and saw a stack of wooden posts and boards, two shovels, and a large hammer.

"You are going to help me build a fence," he said.

I took a deep breath. It was going to be an **arduous** day.

7 Based on the passage, what is the definition of **arduous**?

- A. building
- B. tiring
- C. relaxing



An Instrument for Designing and Modifying Assessment Items

TAMI: Purpose

- This evaluation tool is designed to facilitate a comprehensive analysis of test items for the purpose of enhancing access and meaningful responses from all students. The content is organized into 6 sections based on key parts and dimensions of an item.
 - ♦ **Passage / Stimulus**
 - ♦ **Item Stem**
 - ♦ **Visuals**
 - ♦ **Answer Choices**
 - ♦ **Page / Item Layout**
 - ♦ **Fairness**
- Many existing test items can be improved with regard to (a) aspects of access (b) content relevance and difficulty, and (c) fairness.
- By using TAMI systematically, items can be improved to enhance testing practices and tests for many more students.

Overview of TAMI Content

1. Passage / Stimulus

- 1.1 Passage and/or stimulus vocabulary is grade-appropriate;
- 1.2 Passage and/or stimulus sentence complexity is grade-appropriate;
- 1.3 Idioms or jargon are avoided (unless they are defined and related to the item content);
- 1.4 Sentence structure is as simple as possible given the construct being measured;
- 1.5 Text includes only words essential for responding to the item, with minimal extraneous verbiage;
- 1.6 Essential words or vocabulary terms use **bold** font to facilitate identification;
- 1.7 Readability analyses indicate appropriate grade level;
- 1.8 Passage or stimulus minimizes construct irrelevant knowledge and skills that are necessary for item response;
- 1.9 Passage and/or stimulus is viewable on the same page as visuals, item stem and answer choices;
- 1.10 Other: _____

2. Item Stem

- 2.1 Item stem reflects intended content standard(s) and/or objective(s);
- 2.2 Item text consists of commonly used words (with the exception of tested vocabulary);
- 2.3 Text includes all requisite information for responding;
- 2.4 Text includes only words essential for responding to the item, with minimal extraneous verbiage;
- 2.5 Readability analyses indicate appropriate grade level;
- 2.6 Item vocabulary is grade-appropriate;
- 2.7 Sentence complexity is grade-appropriate;
- 2.8 Idioms or jargon are avoided (unless they are defined and related to the item content);
- 2.9 Essential words or vocabulary terms use **bold** font to facilitate identification;
- 2.10 Item stems are positively worded (i.e., avoiding not questions);
- 2.11 Question or directive is written clearly;
- 2.12 Other: _____

Definition of Accessibility

The extent to which an environment, system, or product eliminates barriers and permits equal access to all components and services for all individuals.

3. Visuals

- 3.1 Visuals are relevant to essential item content;
- 3.2 Every visual is connected to the text (e.g., pictures, graphics, direction icons);
- 3.3 Visuals clearly represent intended images;
- 3.4 Visuals have sufficient contrast between colors;
- 3.5 Visuals convey information using more than distinctions between colors;
- 3.6 Essential words or vocabulary terms use **bold** font to facilitate identification.
- 3.7 Visuals include labels and supportive text if necessary (e.g., titles, row and column headers for graphs).
- 3.8 Circles, arrows, or highlighting are used for important elements of visuals.
- 3.9 Supportive text is located close to related visuals;
- 3.10 When visuals are self-explanatory, words are not added;
- 3.11 Other: _____

4. Answer Choices

- 4.1 Text includes only words essential for responding to the item, with minimal extraneous verbiage;
- 4.2 All answer choices are about equal in length;
- 4.3 All distracters are plausible ("attractors");
- 4.4 All answer choices (of a multiple choice item) are necessary;
- 4.5 No distracters could be eliminated without reducing the validity of the inference(s) permitted by the item;
- 4.6 The order and construction of the answer choices is deliberate;
- 4.7 Other: _____

5. Page / Item Layout

- 5.1 All text is printed in standard typeface, using a minimum of 12-point text;
- 5.2 There is sufficient space between lines (leading);
- 5.3 There is high contrast between text and background colors;
- 5.4 All text can be read in a traditional, left-to-right, top-to-bottom way, with consistent left-margins;
- 5.5 Text is formatted appropriately with regard to breaks and unbroken blocks;
- 5.6 The entire item (stimulus, visuals, stem and answer choices) is visible on the same page/screen;
- 5.7 Page includes ample white space to prevent the item from appearing cluttered;
- 5.8 Right margin is unjustified (staggered);
- 5.9 Visuals are integrated into the item stimulus and item stem, rather than placed off to the side;
- 5.10 Other: _____

6. Fairness

- 6.1 Item content shows respect for different groups as defined by societal roles, beliefs, ethnicities, genders, disabilities, etc.;
- 6.2 Item minimizes construct-irrelevant knowledge and skills that may make the item more difficult for some test-takers regardless of the construct being measured;
- 6.3 Item avoids material that may unnecessarily evoke emotion or controversy;
- 6.4 Item uses appropriate terminology to describe individuals and groups;
- 6.5 Item avoids stereotypes, overgeneralizations, and oversimplifications when characterizing individuals and groups;
- 6.6 Item equally represents, to the extent possible, both men and women and a variety of races and ethnicities;
- 6.7 Other: _____

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The Anatomy of an Item

Item & Page
Layout

Mr. Murphy drives his car to work three days per week.

How many miles does Mr. Murphy drive to and from his job each week?

A. 200 miles
B. 60 miles
C. 120 miles

Item
Stimulus

Visual

Item
Stem

Answer
Choices

TAMI Item Worksheet

Content Area / Item #:					Target Construct / Skills:
CATEGORY	ACCESSIBILITY RATING				MODIFICATIONS FOR IMPROVEMENT
1. Passage / Stimulus	0	1	2	3	Passage / Stimulus:
2. Item Stem	0	1	2	3	Item Stem:
3. Visuals	0	1	2	3	Visuals:
4. Answer Choices	0	1	2	3	Answer Choices:
5. Page / Item Layout	0	1	2	3	Page / Item Layout:
6. Fairness	0	1	2	3	Fairness:
Total Accessibility Rating: (Possible Range: 0 - 18)					Overall:
Integrated Summary of Recommended Modifications:					
Final Changes:					

Key Sources

- Cognitive Load Theory and Instructional Design: Recent Developments (*Educational Psychologist*, Paas, Renkl, & Sweller, 2003)
- *Efficiency in Learning* (Clark, Nguyen, & Sweller, 2006)
- TAMI (Beddow, Kettler, & Elliott, 2008; visit <http://peabody.vanderbilt.edu/tami.xml>)