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Training and Practice Requirements for NDE: Basic Research in Human Learning and Memory

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Introduction

- Changes in ASME Code Section XI, Appendix VII (2011) reduced experience hours required for Level II certification from 800 to 400, permitting 320 hours of laboratory training. (Table VII-4110-1, Required Experience for Initial Certification for Ultrasonic Examination (Hours))
- Use of this revised version of the Code for training hours is prohibited, as the impact of reduced training and nuclear plant familiarization is unknown.
- Code also requires a minimum of 8 hours of practice on samples similar to those encountered during in-service inspections. No examination is required.
- NRC initiated contract research to investigate technical basis for training requirements through a scientific literature review of studies concerning human learning, retention, training, and application of knowledge.
- Product – integrative literature review and recommendations concerning technical basis for NDE training hours and types.

Principal Messages

- The issue of field experience hours is amenable to analysis through the discipline of cognitive psychology
- There are fundamental mechanisms and principles governing human learning and memory
- These fundamental principles are applicable to instruction and technical training
- For learning and retention, more time is better, and how that time is spent matters

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Outline

- Background – research questions, models, methods
- Structure and functions of memory
- Learning processes and principles
- Simulation as a learning tool
- Implications for NDE training
- Next steps to apply the basic research

Background

- Required criteria for most professions based on a combination of the following:
  - Historical practice
  - Expert practitioner judgment
  - Time and cost to develop and maintain expertise
- Applied research questions
  - How many hours are required to become proficient?
  - What kinds of hours are required (field, classroom, lab)?
  - How much and what kind of retraining or practice are necessary, over what period?
    - ✓ Maintain competency
    - ✓ Enhance competency

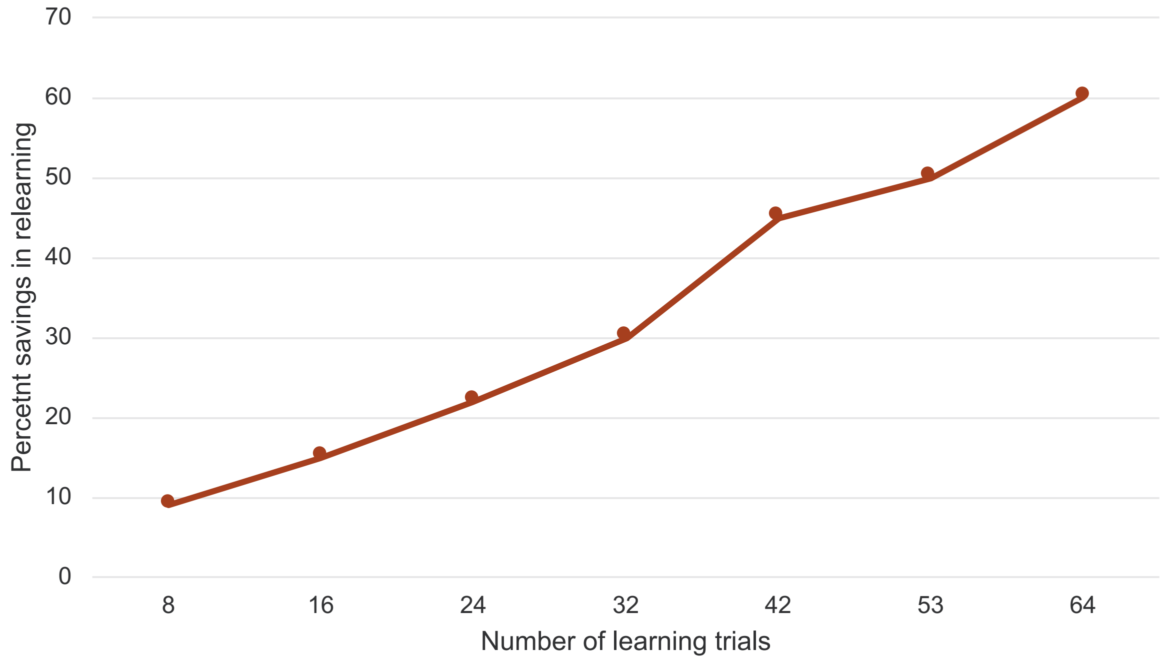
Research Perspectives

- Basic Science of Learning
  - Study of how people learn
  - Goal is research-based theory of how people learn – fundamental processes
- Science of Training & Instruction
  - Study of how to help people learn
  - Goal is research-based principles of instructional design - which methods work for teaching which kind of knowledge to which kinds of learners under which kinds of circumstances
- Science of Expert Performance
  - Study domain experts
  - Goal is understanding development and maintenance of expertise

Basic Science: Experimental Psychology of Verbal Learning and Memory

- Abstracts processes of interest and studies under controlled conditions
- Define fundamental principles that are likely to apply across many circumstances
- List memorization and re-learning

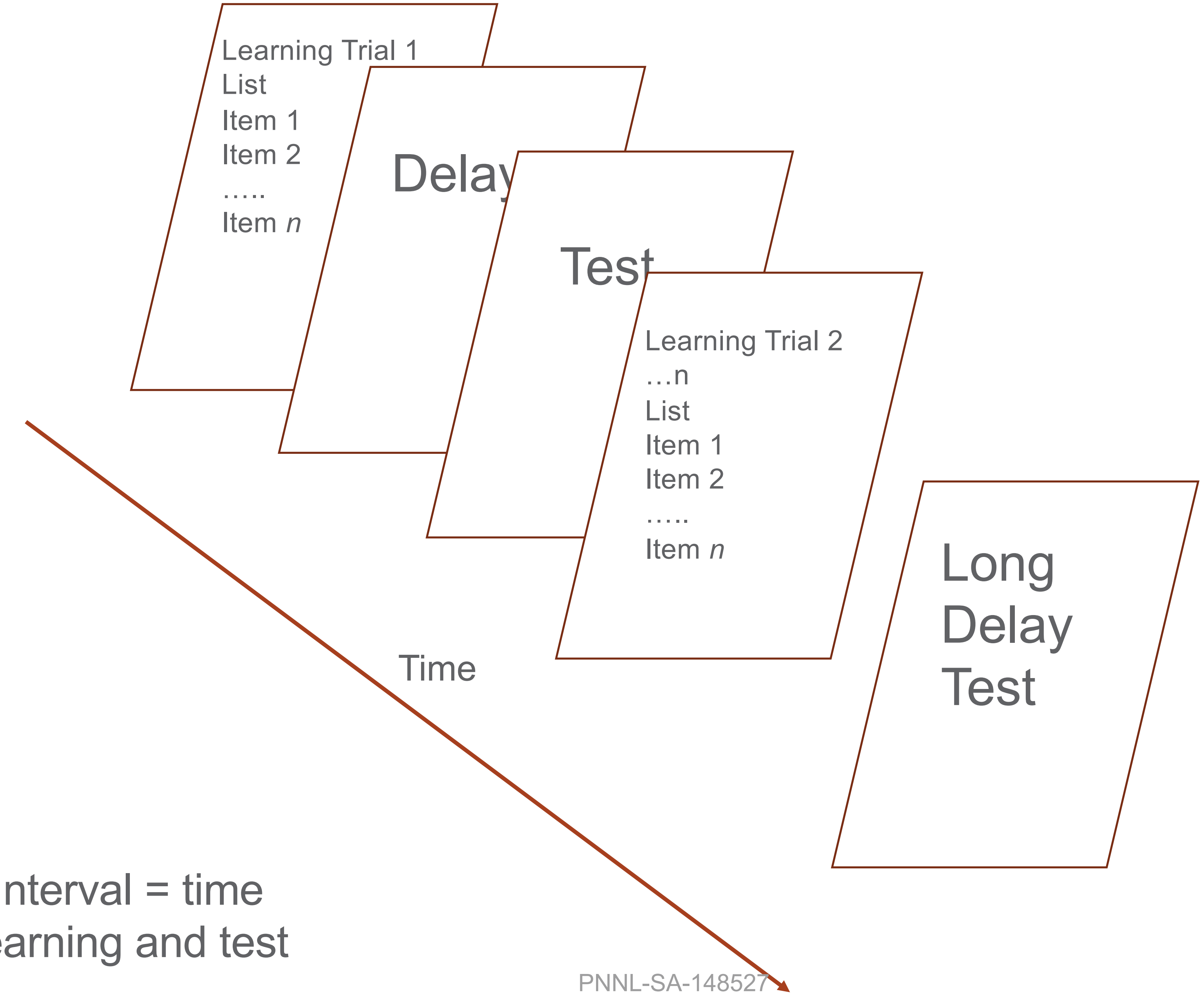
Hermann Ebbinghaus (1850 – 1909)



Percentage saved in re-learning needed to master a list of 16 syllables 24 hours after various amounts of initial study. (% Savings = (# learning original learning trials) - (# re-learning trials)/(# original learning trials)

Nonsense syllable examples - DAX, BOK, YAT

Structure of Typical Learning and Memory Experiment



- Learning Factors:
  - List length
  - Type of Material
  - Study time
  - Repetitions
  - etc.
- Learning Measures:
  - Time to criterion performance (e.g., mastery)
  - Percent correct performance
  - Percent information retained over time
  - Percent errors
  - Performance improvement over time

Retention Interval = time between learning and test

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Memory

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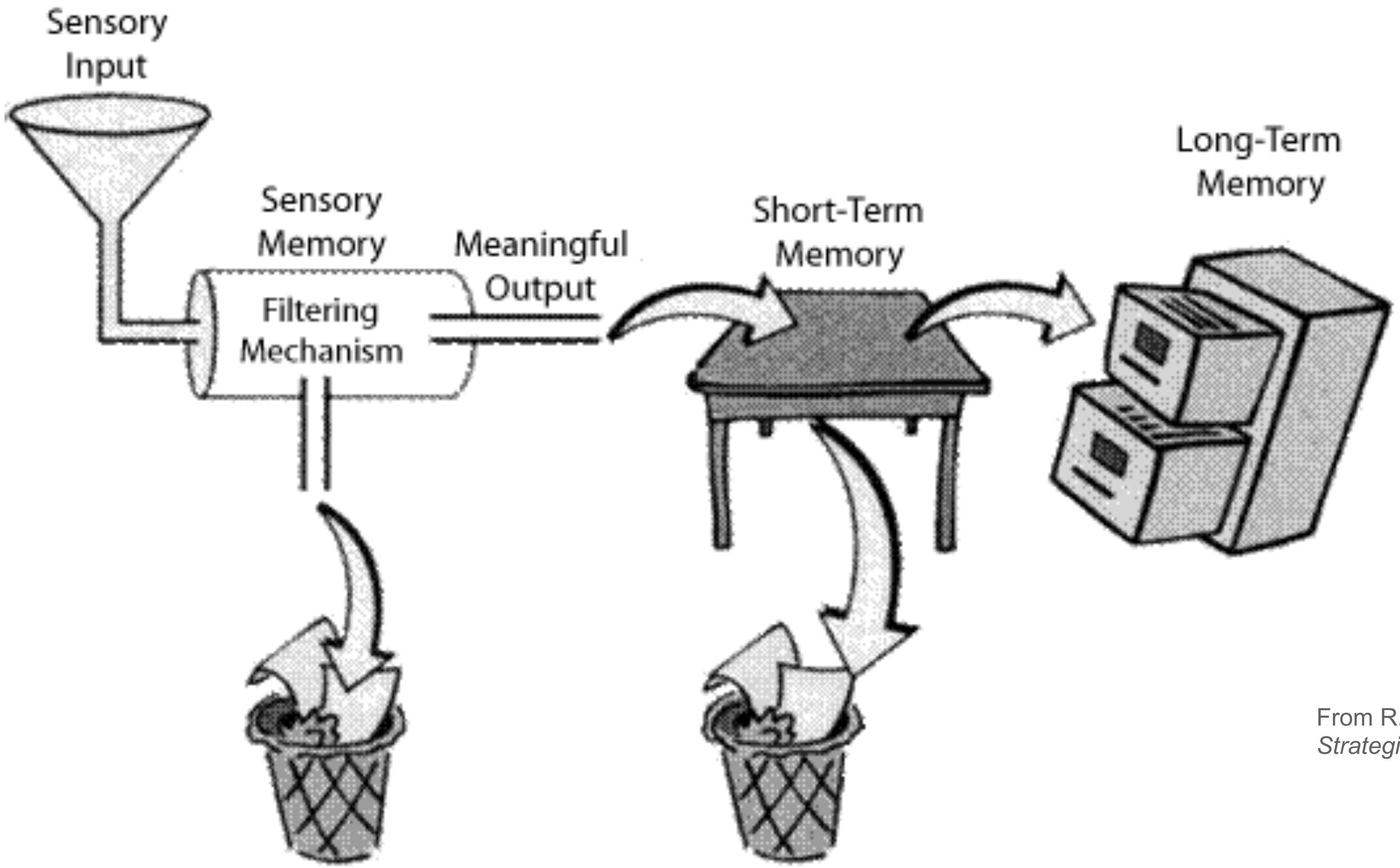
Structure and Functions of Memory

- Memory defined - process by which humans maintain and access the whole range of personal experiences, academic learning, and non-verbal memories involving other senses such as sound, touch, taste, movement, and emotional responses
  - Non-verbal memories compelling
- Functional performance models – describe memory in terms of transformations of input and output, factors that influence performance, hypothetical intervening processes
- Neural processes underlie memory, help to differentiate types
  - Unnecessary to describe neural mechanisms if focus is on performance

Immediate (short-term) and long-term memory



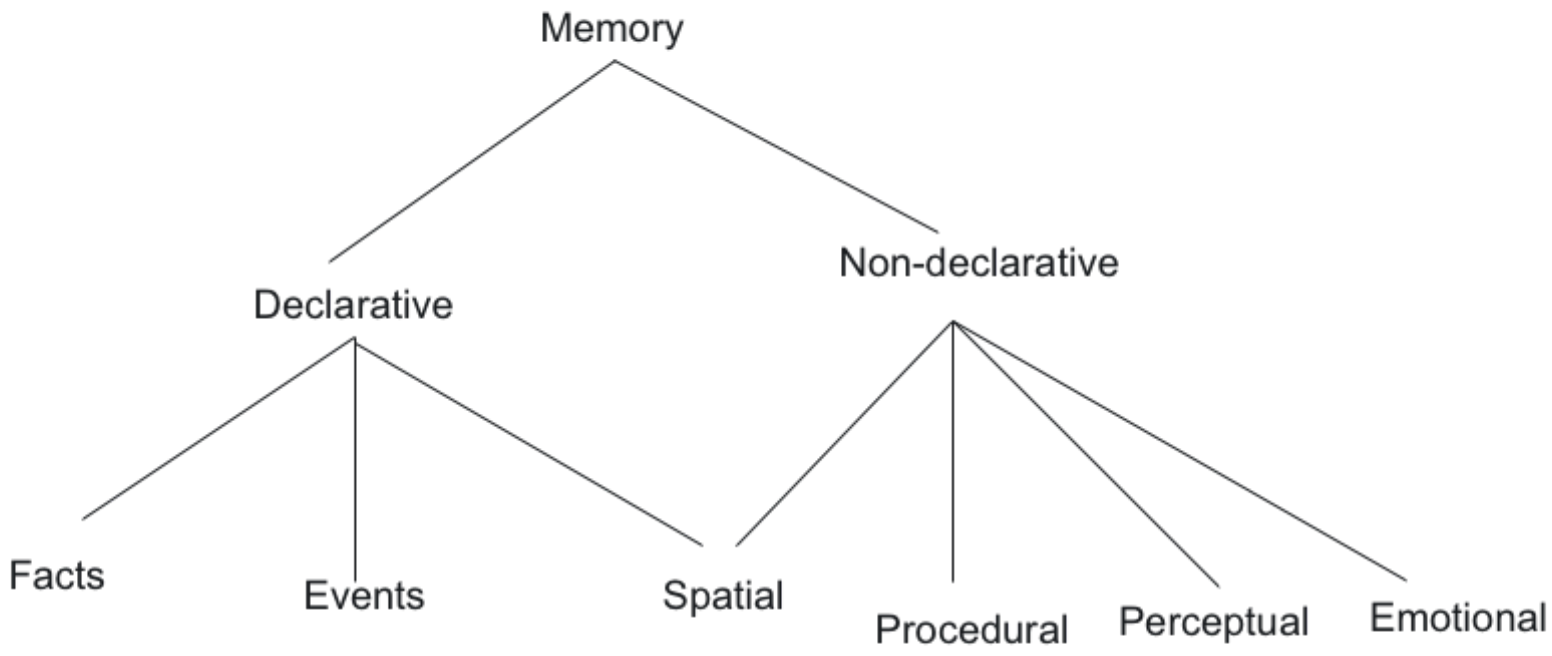
From R. Richards, *The Source for Learning and Memory Strategies*. LinguiSystems, 2003, p. 17.

Short-term (Working) Memory

- Current focus of task attention
- Limited capacity – 3 to 4 “chunks” of information
- Limited duration (< 1 minute)
- Typically used for holding information in mind while doing a task (e.g., dialing phone number)
- Considered to be the focus of current awareness – and contains subset of information from long-term memory
- Capacity can be increased through training
  - Experts are able to hold more information in short-term memory if it pertains to expert task performance

Long-Term Memory

- Multiple functional systems
- Unlimited capacity
- Declarative
  - Facts
  - Personal History
  - Conscious
- Non-declarative
  - Implicit
  - Often below level of awareness



Perceptual Representation System

- Memory for perceptual features – word/image fragments, objects, patterns, etc. – based on past exposure
- Often below level of awareness
- Perceptual features – lines, corners, angles, clusters
  - Aids in quick recognition of patterns
  - Identify signals (perceptual features) in noise
  - Perceptual learning used in image analysis, surgical procedures, NDE, navigation
  - Training perceptual elements
  - Changes in environmental perceptual features can impede navigation

Perceptual Learning “an increase in the ability to extract information from the environment, as a result of experience and practice with stimulation coming from it”

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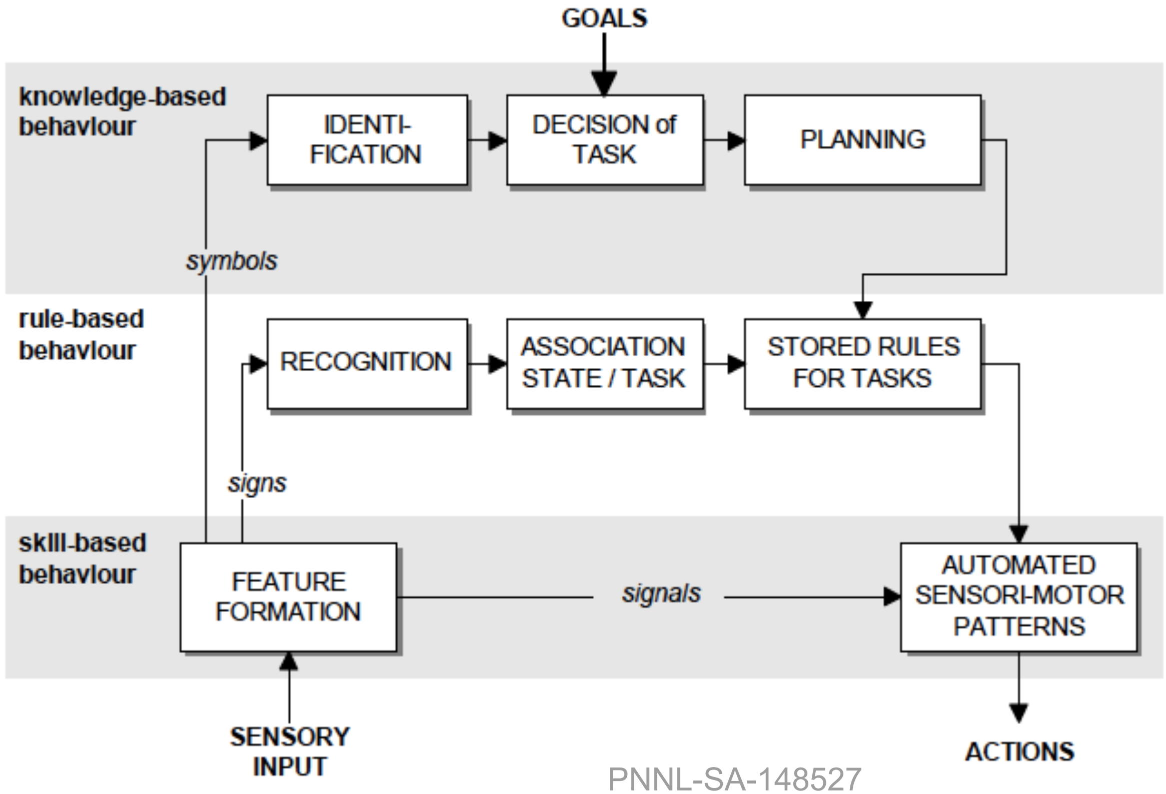
Procedural Memory

- Memory for sequential operations that people are able to execute without conscious recollection of individual steps or elements is considered *procedural*
- Develops over a period of practice, and the specific perceptual-motor actions occur without people necessarily being able to verbalize exactly what they are doing
- Examples
  - Knowing proper grammar without being able to explain rules
  - Sequential motions of physical activities without overt awareness (riding bike)
- Knowing “how” versus knowing “what”

Procedural Memory (continued)

- Develops through stages: initially deliberate and slow, increasing association between inputs and outputs, reaching autonomous stage of direct linkage between sensory inputs and appropriate responses
- Knowledge (deliberate, slow), Rule (increasing association), Skill (autonomous)



Knowledge-Rule-Skill Hierarchy (Rasmussen 1983)

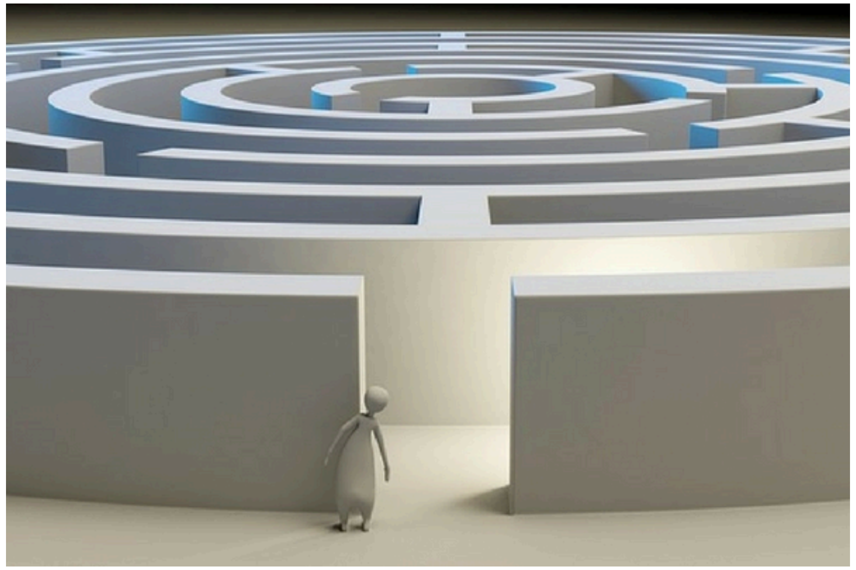
Declarative Memory

- Knowing "what" – recollection of facts, order, relationships. Basis for traditional educational curricula.
- Two basic types
  - Semantic – factual knowledge, categories, concepts,
    - ✓ Types and habits of salmon
  - Episodic – self-referential, judgments about events or material on basis of whether we have experienced them before.
    - ✓ When & where I last caught a salmon

Episodic	Semantic
Events, occurrences	Facts, ideas, concepts
Organized temporally	Organized conceptually/hierarchically
Memory more context dependent	Memory less context dependent
Experience of remembering	Experience of knowing
Illustrates examples of general education material	Structures representation of general education material

Spatial Memory and Navigation

- A blend of declarative and procedural systems – “cognitive maps”
- Includes knowledge of
  - Places (e.g., a hill or park)
  - Route (paths between places)
  - Environmental shape (elevations, orientations)
  - Survey (overall configuration in a common reference system)
- Component cognitive processes
  - Recognition of places
  - Learning sequences
  - Identifying decision points
  - Learning appropriate responses
  - Forming associations between places and actions
  - Goal identification within spatial coordinate system
  - Path integration – updating of location, time

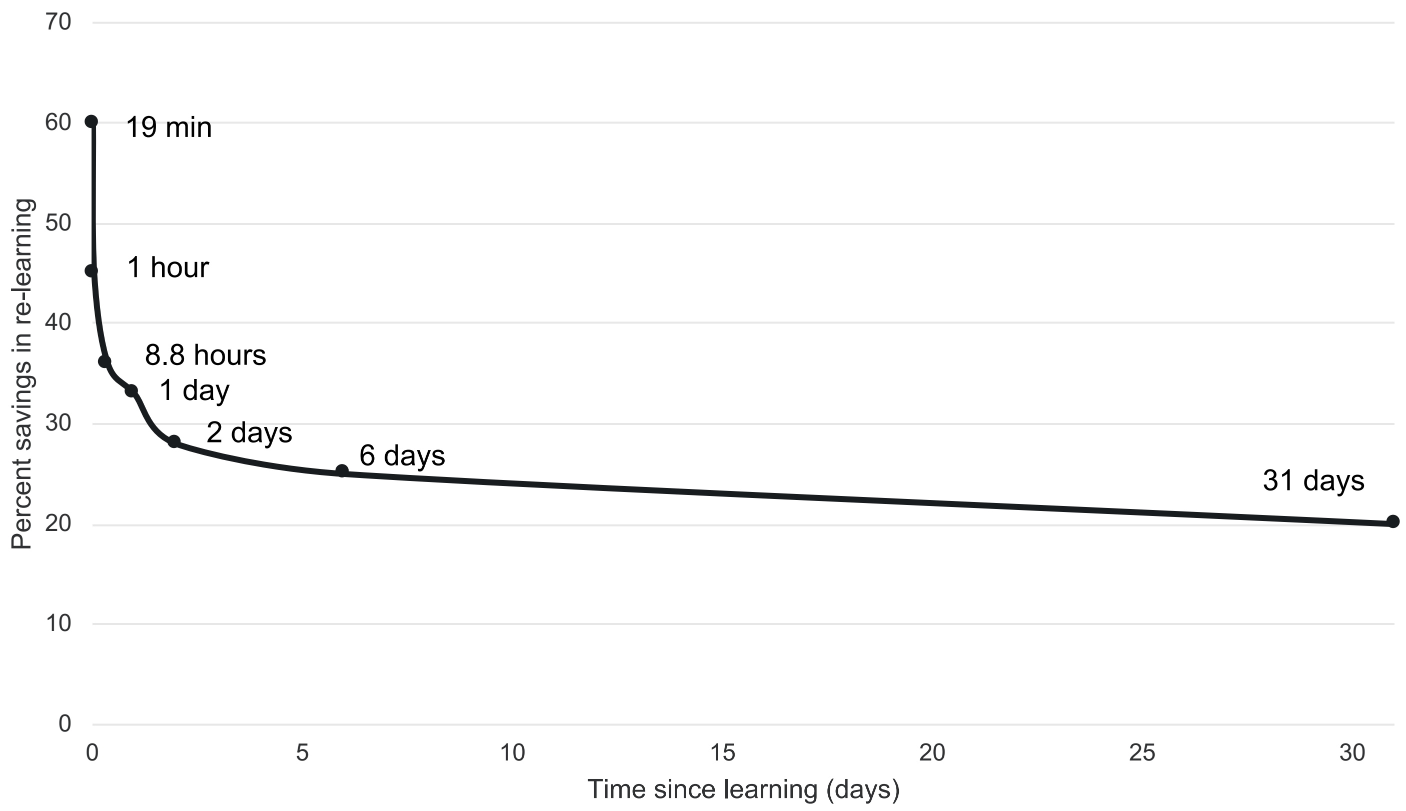


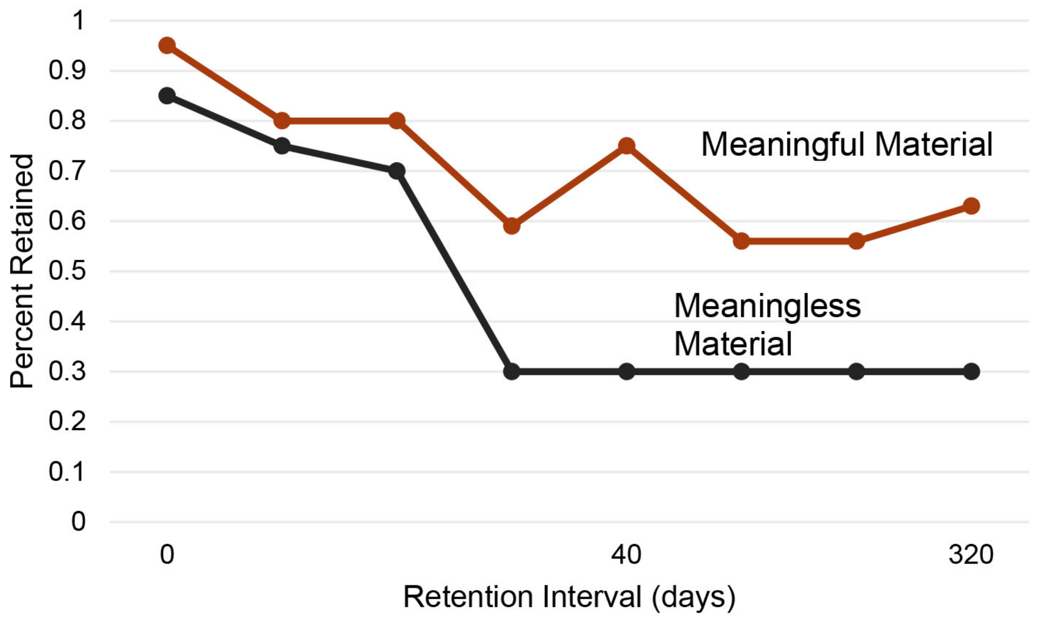
Relevance of Memory Types for NDE Training

- All types used in NDE examinations and training
  - Working Memory – attending to classroom material and processing sensory, cognitive, and instrument manipulations on the job
  - Procedural Memory – executing procedures
  - Perceptual Representation System – recognizing patterns
  - Semantic Memory – organizes knowledge such as geometric reflectors and properties of sound
  - Episodic Memory – examiner experience in observing patterns in previous inspections
  - Spatial Memory – learning plant layouts, interpreting waypoints and isometric drawings

Forgetting

- Forgetting occurs simultaneously with learning, and is rapid





Percentage saved in re-learning to master a list of 13 nonsense syllables

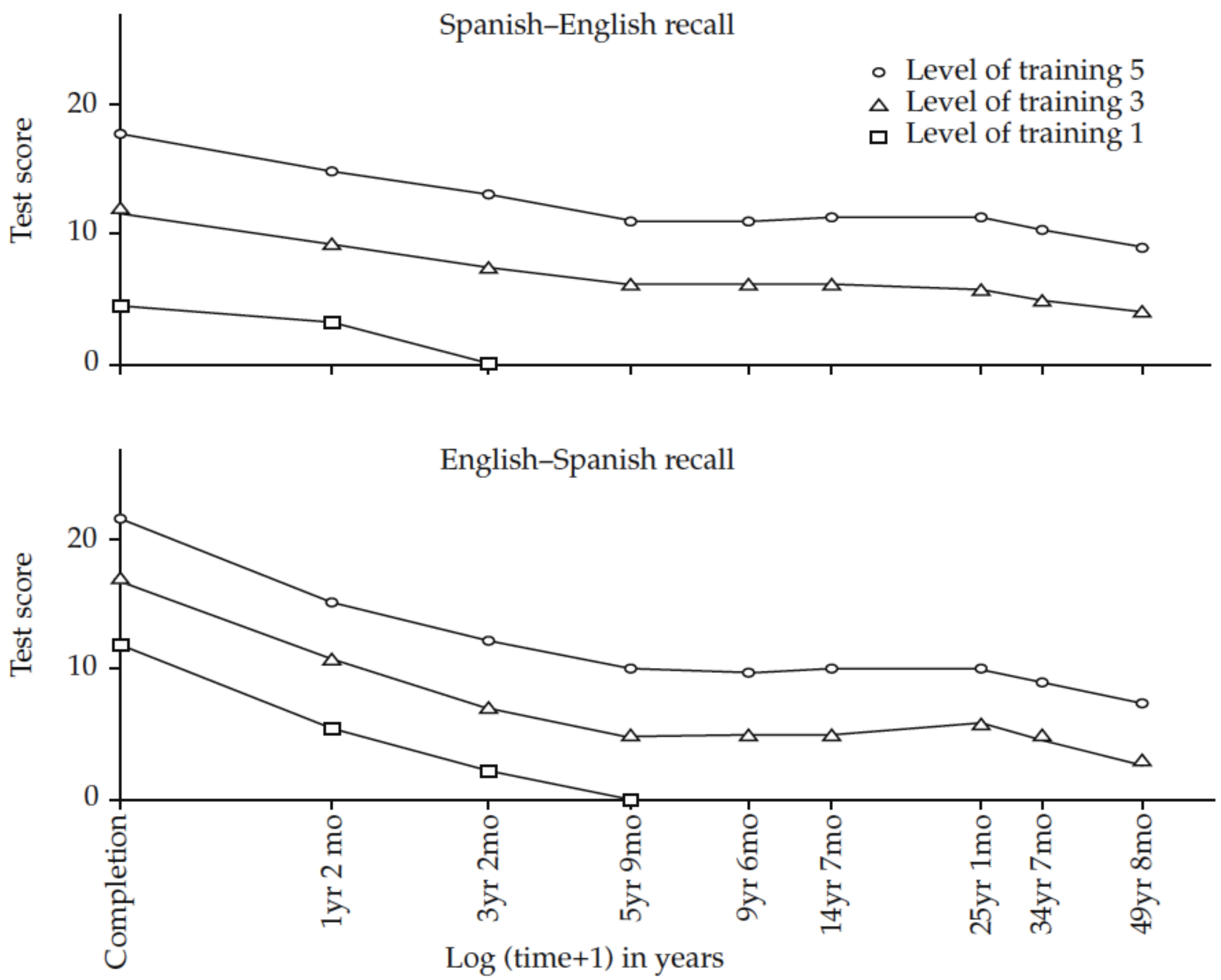
Forgetting is 50% over a day, and 80% over a month

Long-term Retention and Maintenance of Knowledge Over Decades

- Alternative research methods
  - Longitudinal studies not feasible
  - “Cross-sectional” research - groups of people who learned at different points in time allows assessment of retention over many decades (Bahrick, Ohio Wesleyan)
- Groups with studies of Spanish, not practiced since
  - 1 year college
  - 2 years college
  - 4 years college
- Eight groups with 1 – 50 years since completion of study

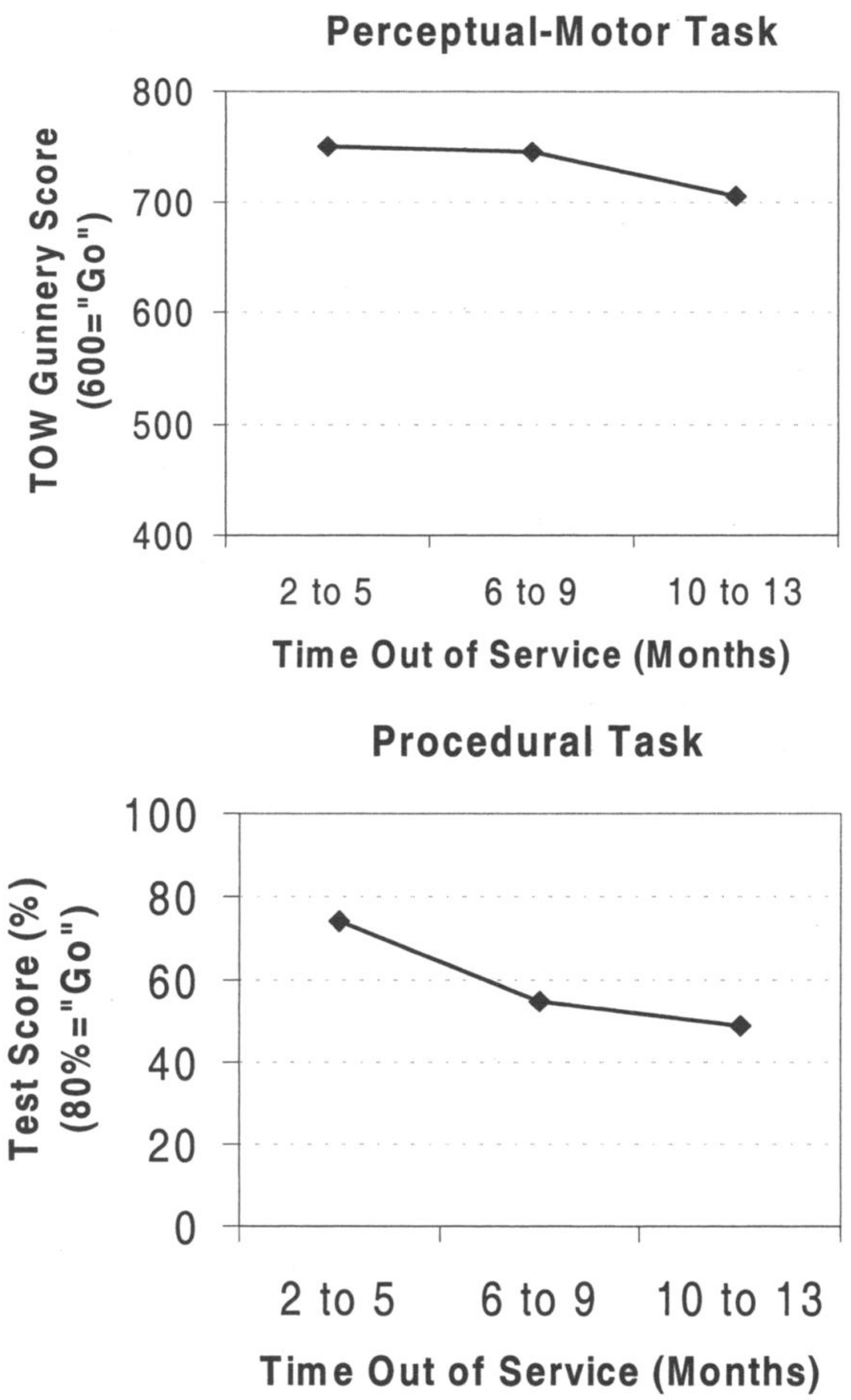
Long Term Retention - Decades

- Performance declined most rapidly in first 5 years after completion of learning
- Highest training level declined from ~75% to 50% at 5 years and stabilized.
- More training = better long-term retention
- Better course grades = better long-term retention
- Numerous studies confirm patterns



Applications: Skill Retention

- Issue: impact of periods of disuse on knowledge and skill
- Mechanism: forgetting of learned material
- Applied studies difficult: most occupations do not entail long periods of disuse
- Military studies – reservists with time out of service
- General finding
  - Continuous motor tasks are relatively resistant to decay
  - Complex procedural tasks involving memory, branching, and contingencies decay rapidly
- Aviation – check pilot study
  - Substantial skill loss in first 8 months – average = 33%
  - Some complex tasks decay more than 50% by 24 months



General Patterns in Long-term Retention of Knowledge

- Academic knowledge shows sharp declines over several years prior to leveling off for up to 35 years
- More training = better retention
- Better course grades = better retention
- Personally acquired knowledge – such as places or friends – is less prone to sharp initial declines

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Learning Processes

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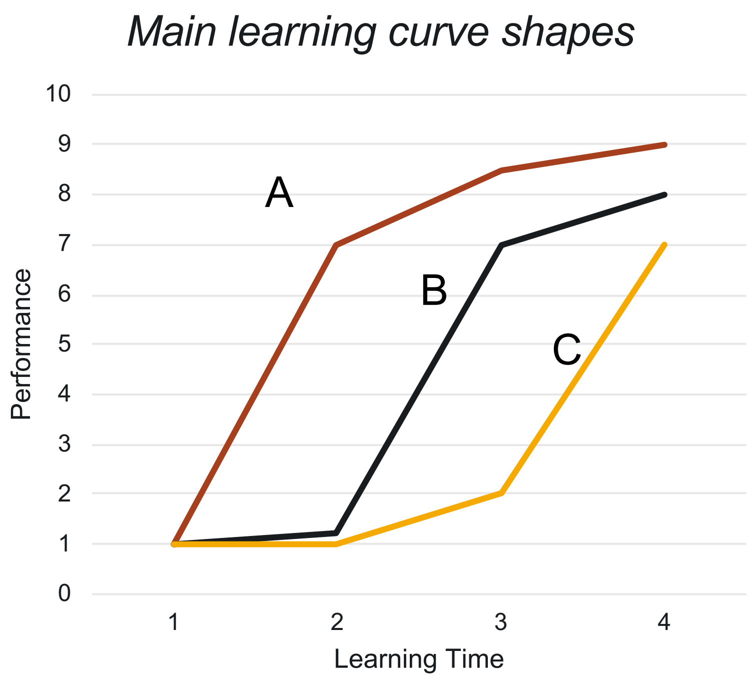
A Definition and Fundamental Principles

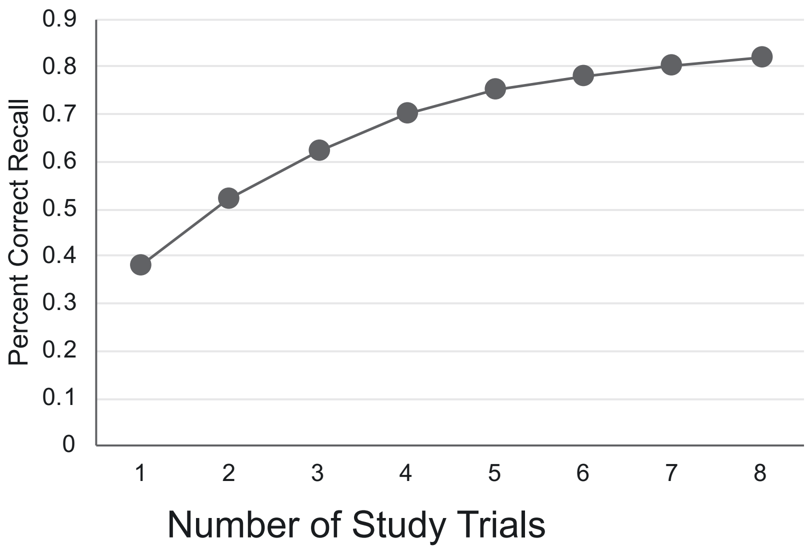
- Learning – a relatively permanent change in behavior resulting from experience, that is distinct from changes in motivation and maturation (growth)

- Total Time: more learning time results in better performance
- Incidental Learning: Learning can occur in the absence of overt behavioral change
- Distributed Practice: Learning time that is distributed across intervals rather than massed together yields better retention
- Knowledge Testing: testing can enhance retention, independent of further study
- Active Learning: More active learning processes result in better retention

Total Time Principle

- Learning takes time, and what is learned is not perfectly retained, and more time is better

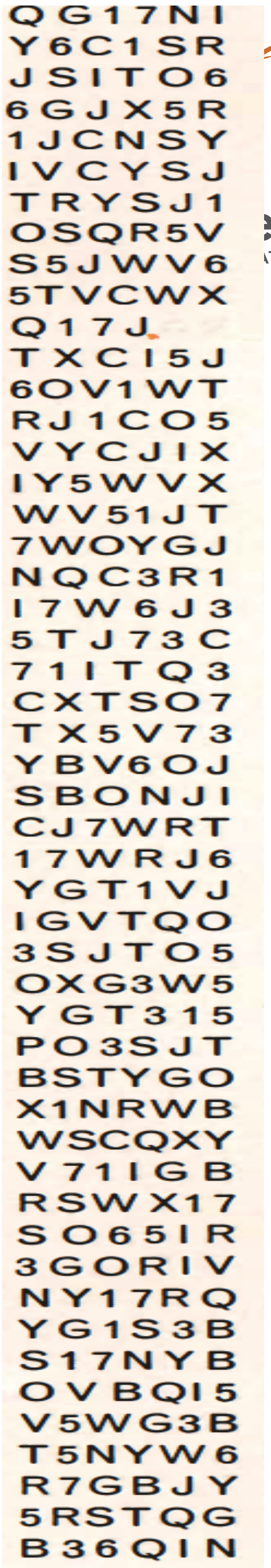




Roediger & Smith, 2012

Interval between learning sessions	13 learning sessions	26 learning sessions
14 days	43	56
28 days	50	68
56 days	57	76

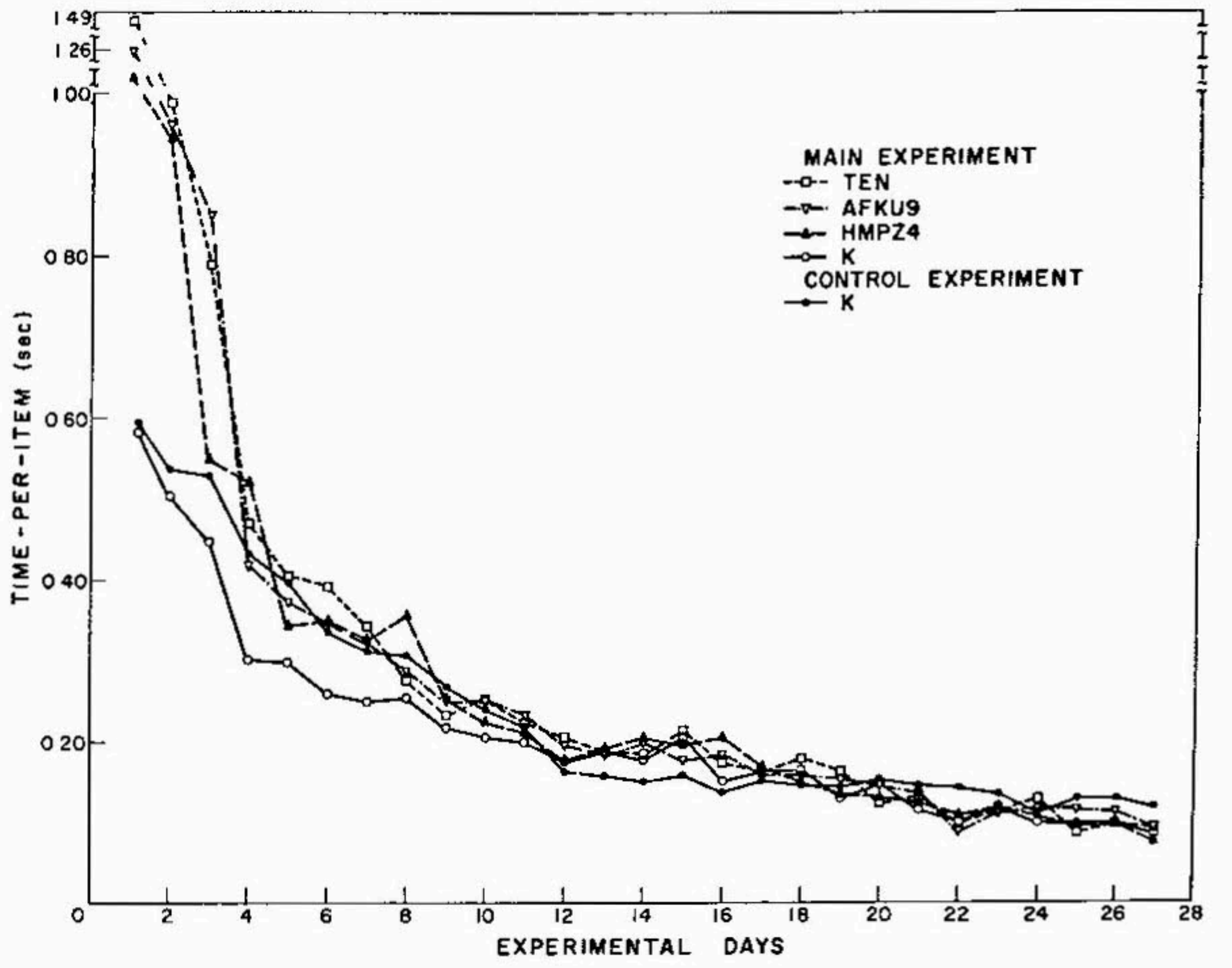
Mean percentage recall as a function of number of sessions and interval between sessions over a 5-year period (Bahrick et al. 1993)



Applications: Experience, Practice, and and the Development of Expert Skill

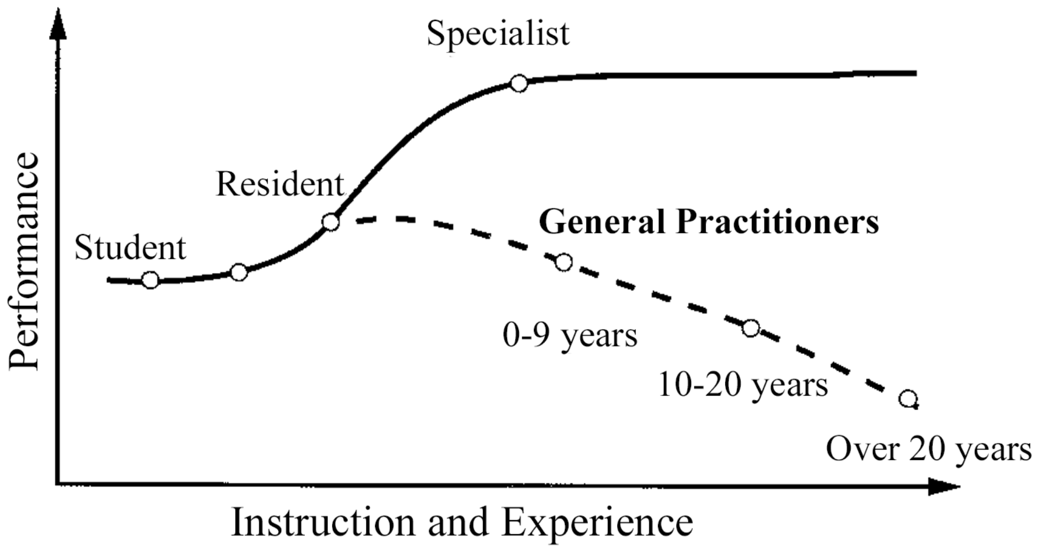
- Studies of tasks analogous to job performance

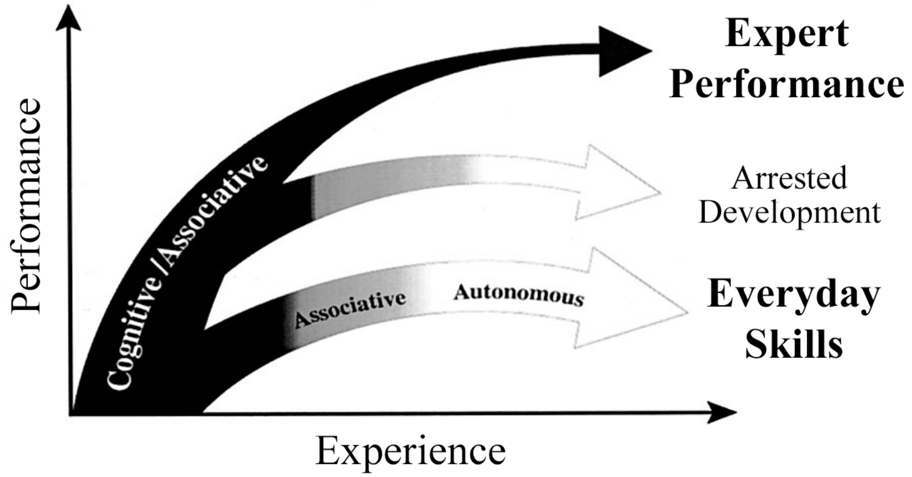
- Visual search improves over time



Applications: Experience, Practice, and and the Development of Expert Skill

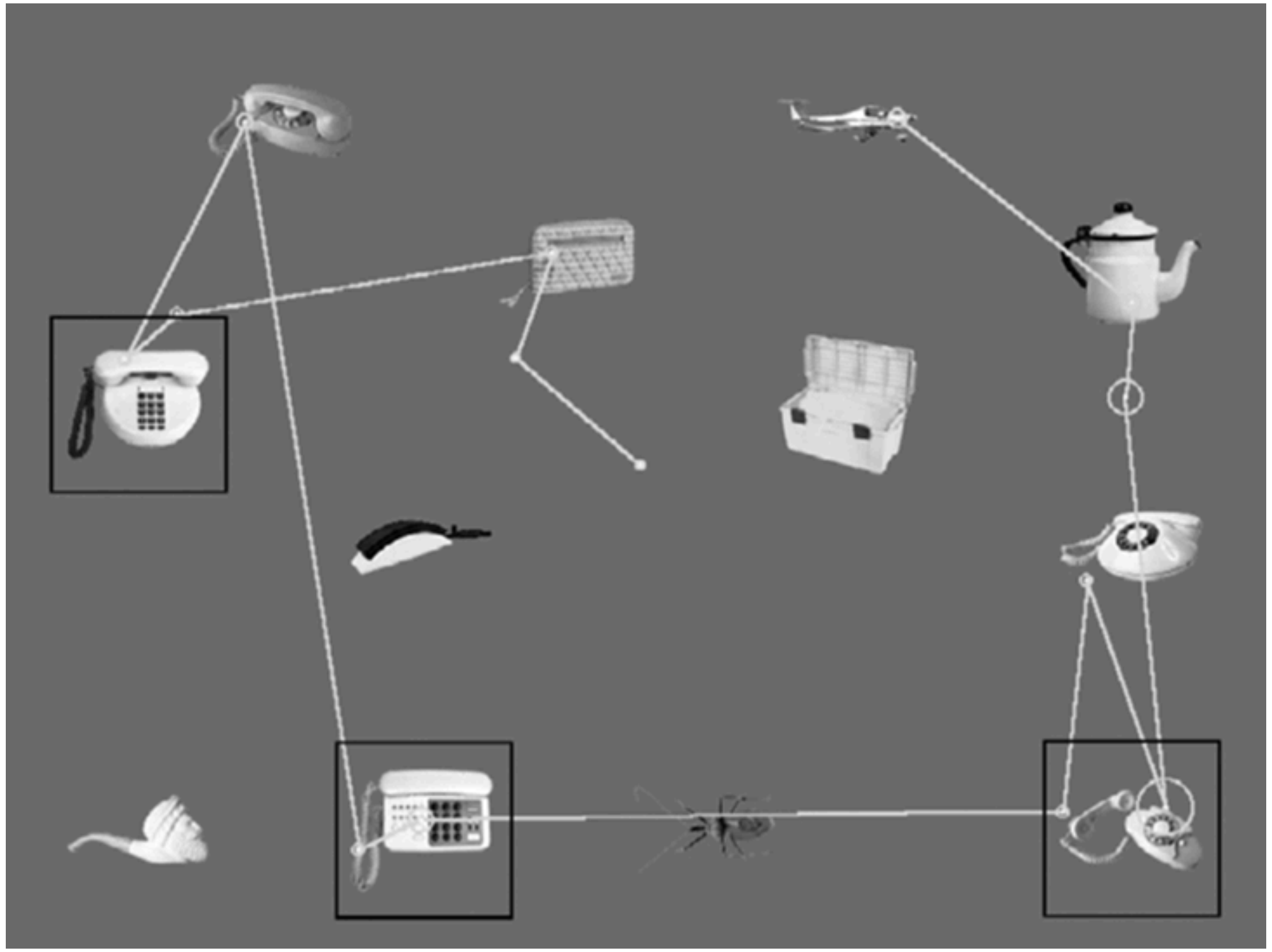
- Specialist diagnostic accuracy increases to 90% compared to students at 30%
- Developing expertise = many hours of daily practice for years, on tasks that challenge current skill level





Incidental Learning

- A secondary consequence of another activity
- "learning which apparently takes place without a specific motive or a specific formal instruction" (McGeoch & Irion, 1952).
  - "Much of the learning of everyday life is of this incidental sort. One drives along a road, walks down a street, meets friends and talks to them, and afterwards remembers much that seems to have been entirely separated from any specific motive [to learn]"
- Example – learning a route to work while riding a bus – there is no engagement or incentive, but when required, people can drive the route
- Incidental learning in visual search
  - analogous to memory for various geometric reflector patterns across multiple plants
  - Relevance to NDE training:
    - ✓ Field experience hours leads to learning that may be incidental to the task at hand
    - ✓ Examiners suggest gradual formation of mental maps ("the first couple of years were a blur….")

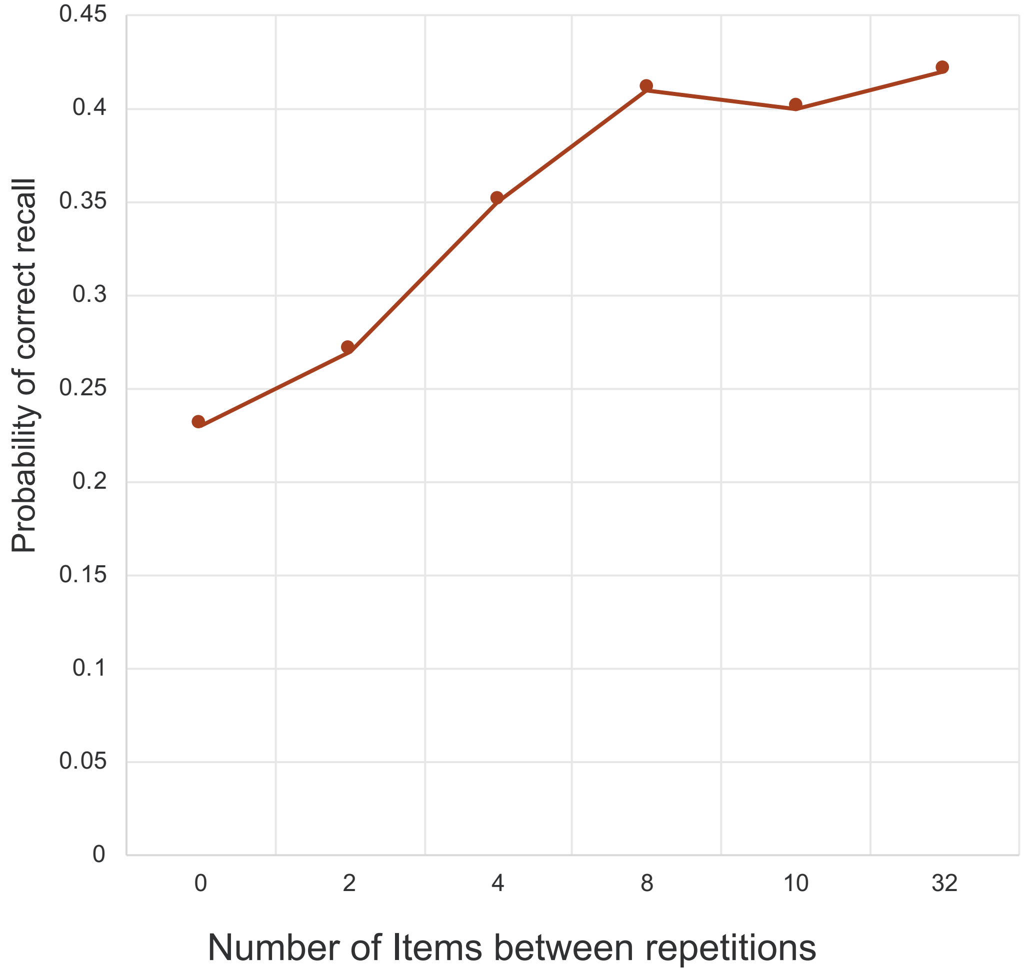


Factors Affecting Learning and Memory

- Time improves learning. How can we enhance the results for the time spent?
  - Practice distribution and variation
  - Testing – independent of additional study
  - Active Learning

Distributed Practice Principle

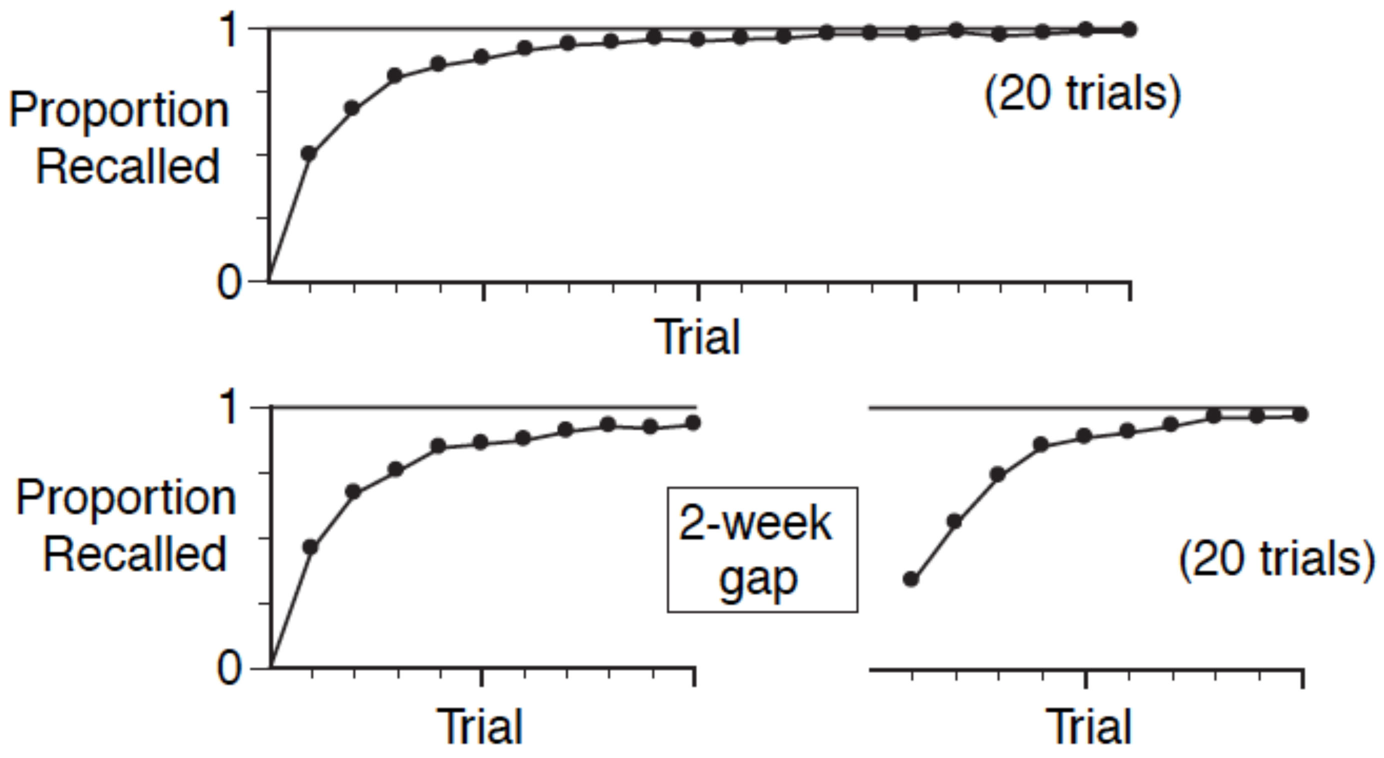
- One of the most robust findings in psychology
- Increased spacing between repetitions of material to be remembered improves performance
- Example: study 2 hours per day over 2 days, instead of 4 hours in a single day
- Applied studies show that distributed learning, although taking more time, leads to superior retention
  - Learning new postal codes
  - Medical courses
  - Language
- Learners perceive this as inefficient, and tend toward massed repetition (e.g., cramming)

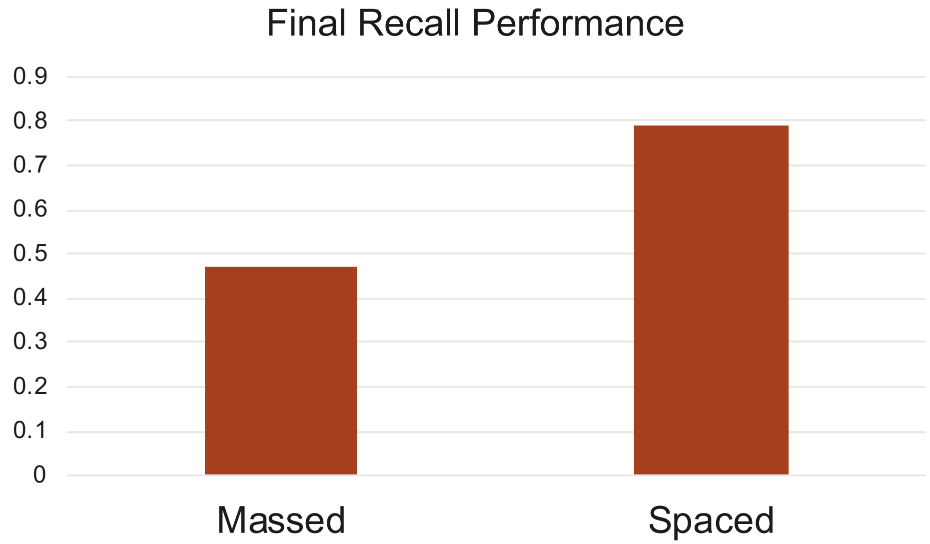


Demonstration

- Direct comparison of massed versus spaced practice
- Learning material = little known story-author pairs (e.g., *A Curious Dream* – Twain)
- Two groups – same number of learning trials –
  - 20 trials massed
  - 10 trials X 2 separated by 2 weeks.
- Memory test two weeks following last learning trial

Results

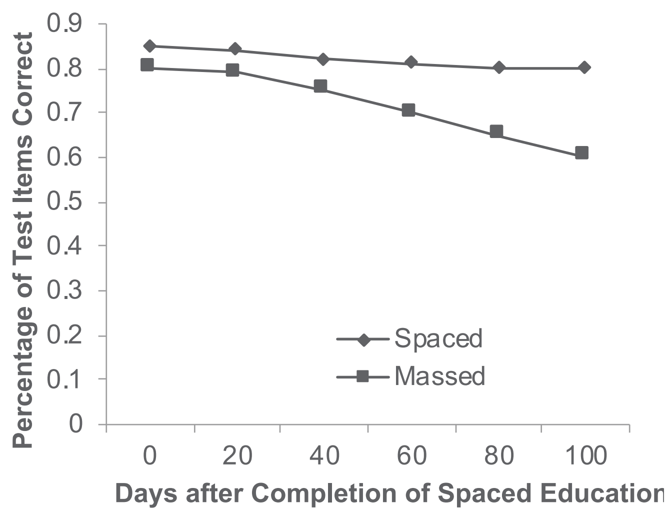




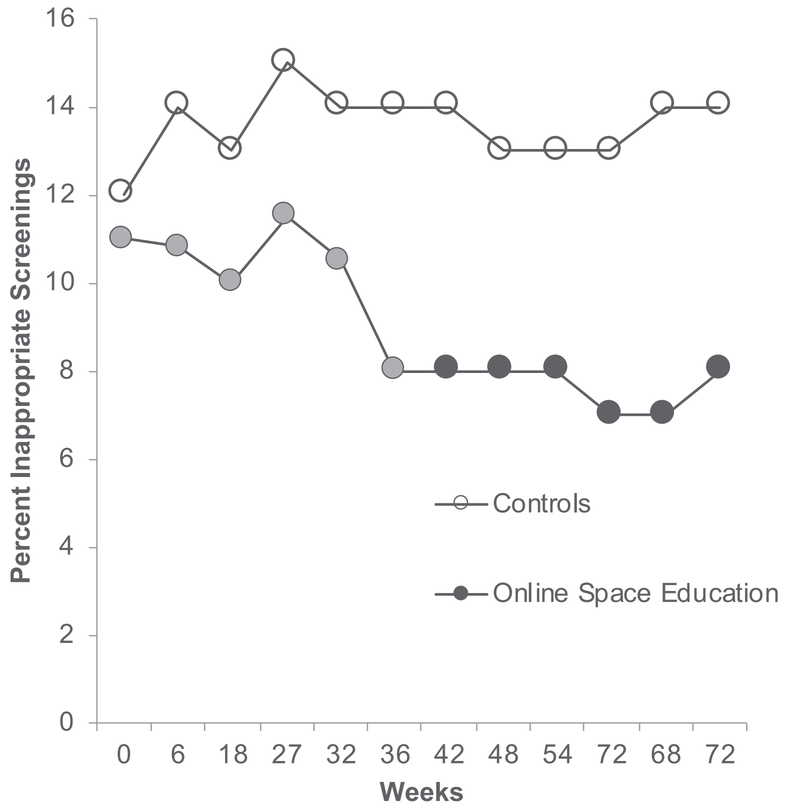
Final Memory test 2 weeks after the last learning trial

Applications: Spaced Education Results

Medical Students: Better long-term retention



Fewer inappropriate tests ordered



Practice/Repetition Schedules

- Longer intervals within the learning-testing time frame enhances retention

Interval between learning sessions	13 learning sessions	26 learning sessions
14 days	43	56
28 days	50	68
56 days	57	76

Mean percentage recall as a function of number of sessions and interval between sessions over a 5-year period (Bahrick et al. 1993)

- For semester-long course, researchers recommend 3+3 approach
  - 3 successful recalls of material at initial learning
  - 3 re-learning sessions spaced throughout the course

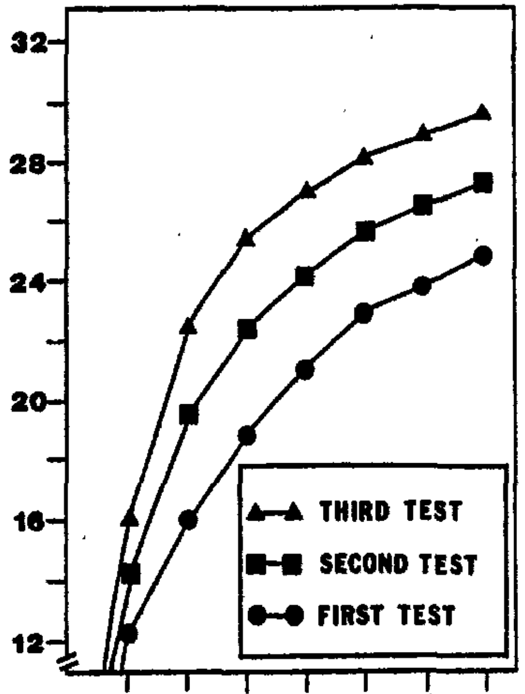
Practice Variability

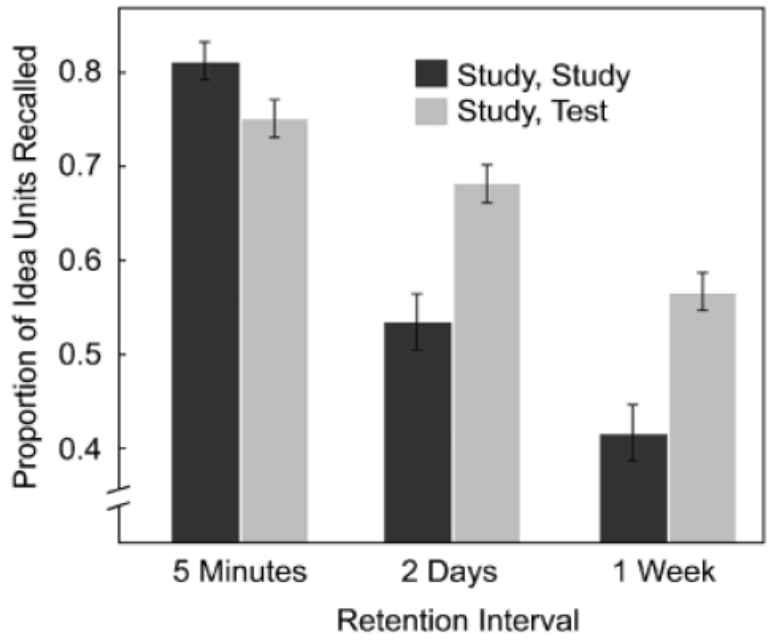
- Practice variation
  - Varying the conditions of practice tends to enhance later performance
    - ✓ Motor skills – such as basket shooting – are improved with variations in practice

- Relevance of spacing and practice studies to NDE training
  - Spaced study sessions show improved performance for many kinds of academic material
  - Spacing of NDE practice may yield better retention than massing the required 8 hours in a single session
  - Alternating practice sample types may yield benefits over blocked practice on a single weld type

Knowledge Testing Principle

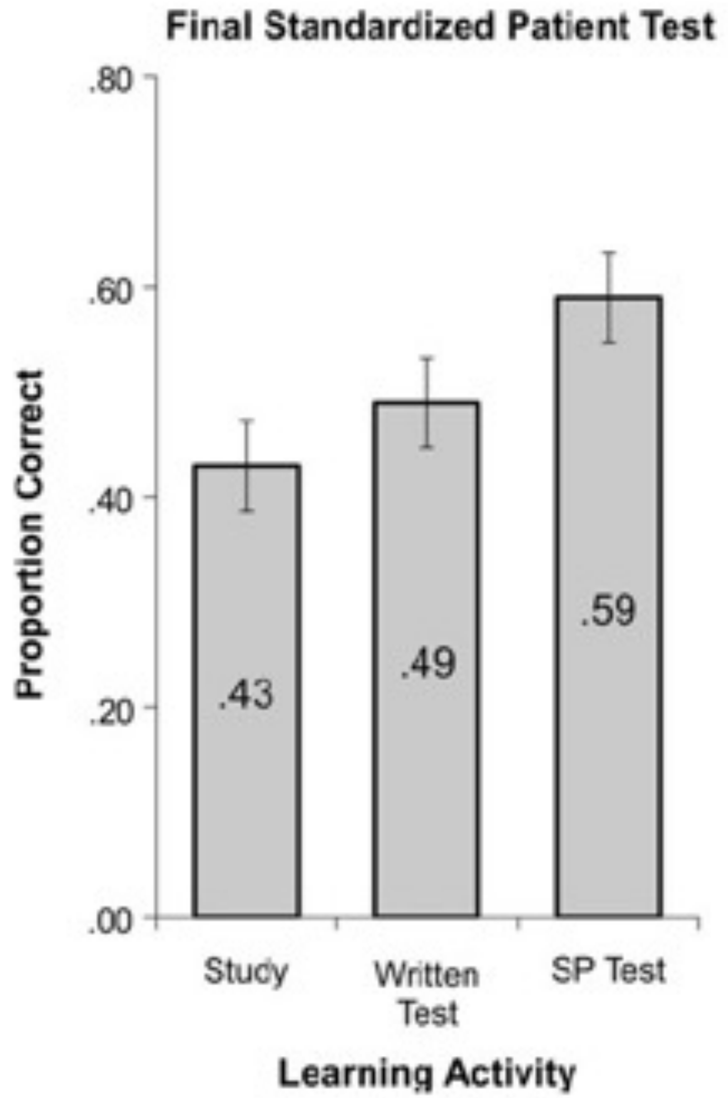
- Repeated attempts to remember previously learned material facilitates retention, without further study
  - Hypermnesia – recovery of material that seems to have been forgotten. “Tip-of-the-tongue” phenomenon
  - Improved recall of material over time without re-study
  - Effect of testing appears to have a direct strengthening effect on memory trace, as no additional study is provided





Applications: Knowledge Testing

- Common classroom techniques: quizzing, clickers (audience response tabulation)
- Medical education studies show advantage of repeated testing using conventional materials (e.g., study sheets, open-ended questions for testing) and testing skills via "standard patient" interactions

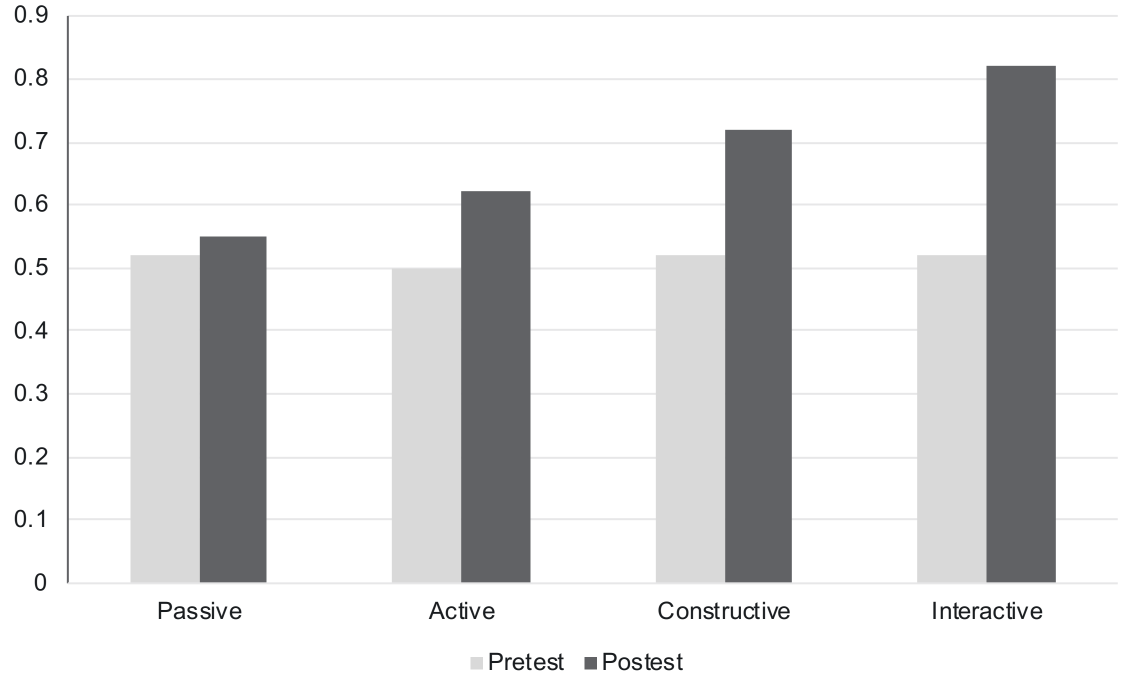


Knowledge Testing Principle (continued)

- Relevance for NDE training
  - Evaluation of retrieval testing in educational settings shows benefits
  - Impact of 8-hour practice requirement might be enhanced if testing were introduced

Active Learning Principle

- Deeper engagement in learning activities leads to better retention.
- Levels of activity
  - Passive – Listening to explanation or watching video
  - Active – Taking verbatim notes, highlighting sentences
  - Constructive – Self-explaining, comparing and contrasting
  - Interactive – Discussing with peer, drawing diagram, concept maps



Simulation

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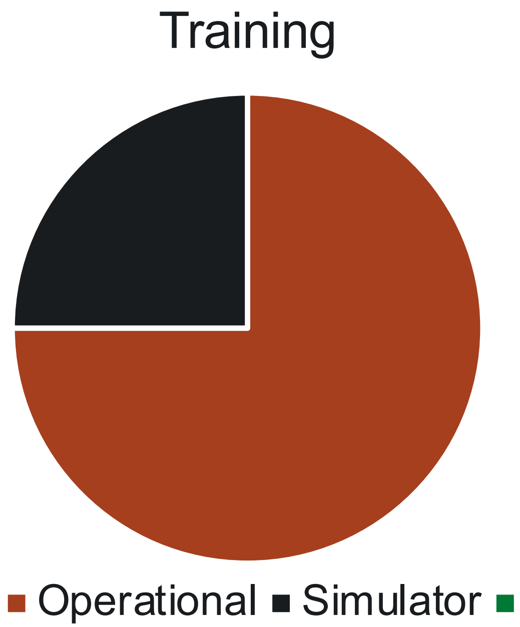
Simulation

- A (computational) model of a process embedded in a physical model
  - Aircraft flight, patient anatomy, driving….
- Lower cost, potentially, than operational devices
  - Scenarios that entail risk
  - Repetition
- Psychological principles
  - Perceptual learning
  - Knowledge of results
  - Stimulus-response learning
- Fidelity less important than training program content
- Fundamental question is extent of transfer, i.e., savings in training in operational environment – the **substitution percentage**

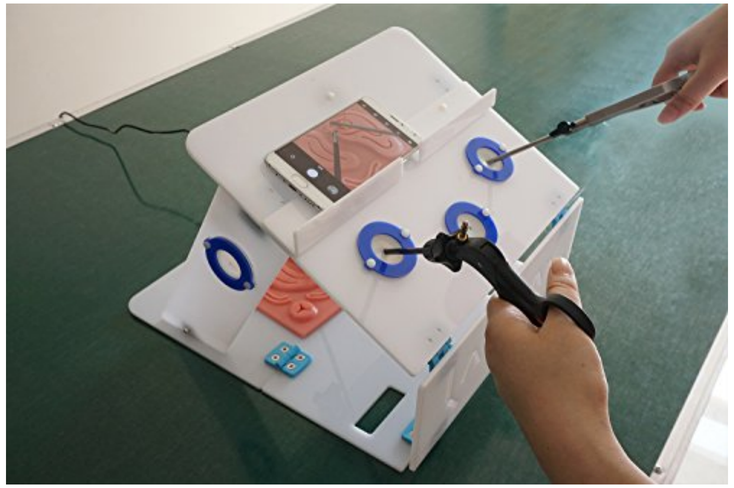


Simulation in Aviation

- Early studies by military report wide range of substitution percentages, 1%–93%
- More recent reviews also found positive transfer for diverse skills – landing skill, bombing, instrument control
- Novice trainees show positive transfer in program using 60% simulator and 40% operational aircraft
- Regulation
  - 1500 hours of flight time
  - No more than 100 hours in a simulator
  - Higher substitution percentages for aircraft type instrument ratings
  - Regulations specify certain experience requirements, e.g., cross-country, night landings, etc.

Simulation in Medicine

- History of simulation – cadavers, animals, role playing, mannequin, VR
- Curriculum standards committees mandate simulation and skill laboratories
- Procedures: tying and suturing, airway management, central venous catheterization, chest tubes, laparoscopy
- Simulator-trained residents show positive transfer to operative setting – no need for senior physician intervention
- No substitution studies
- Little ultrasound simulation



Relevance to NDE Training

- Changes to ASME Code for field experience suggest substitution of lab exercise and simulator work
- Substitution of up to 90% is proposed
- Well beyond any substitution now used or reported in literature
- Unknown fidelity and transfer between lab/simulator and field conditions

Summary & Conclusions

- Basic and applied research literature suggest that reducing training time will reduce learning
  - Lowered study time/retention
  - Less opportunity for distributed practice
  - Less opportunity for knowledge testing
  - Less opportunity for incidental learning
- Literature suggests numerous potential enhancements
  - Perceptual learning
  - Distributed practice
  - Testing

Summary & Conclusions (continued)

- Low base-rate of flaws in operational field experience is problematic
  - Most flaws observed are seen in preparing for PDI
  - Do other non-flaw aspects of field experience warrant 800 hours?
- Simulation literature suggests use as an augmentation to field experience
- More research into current models of NDE/UT training to promote further ideas about application
- Need input from SMEs and trainers

Thank you

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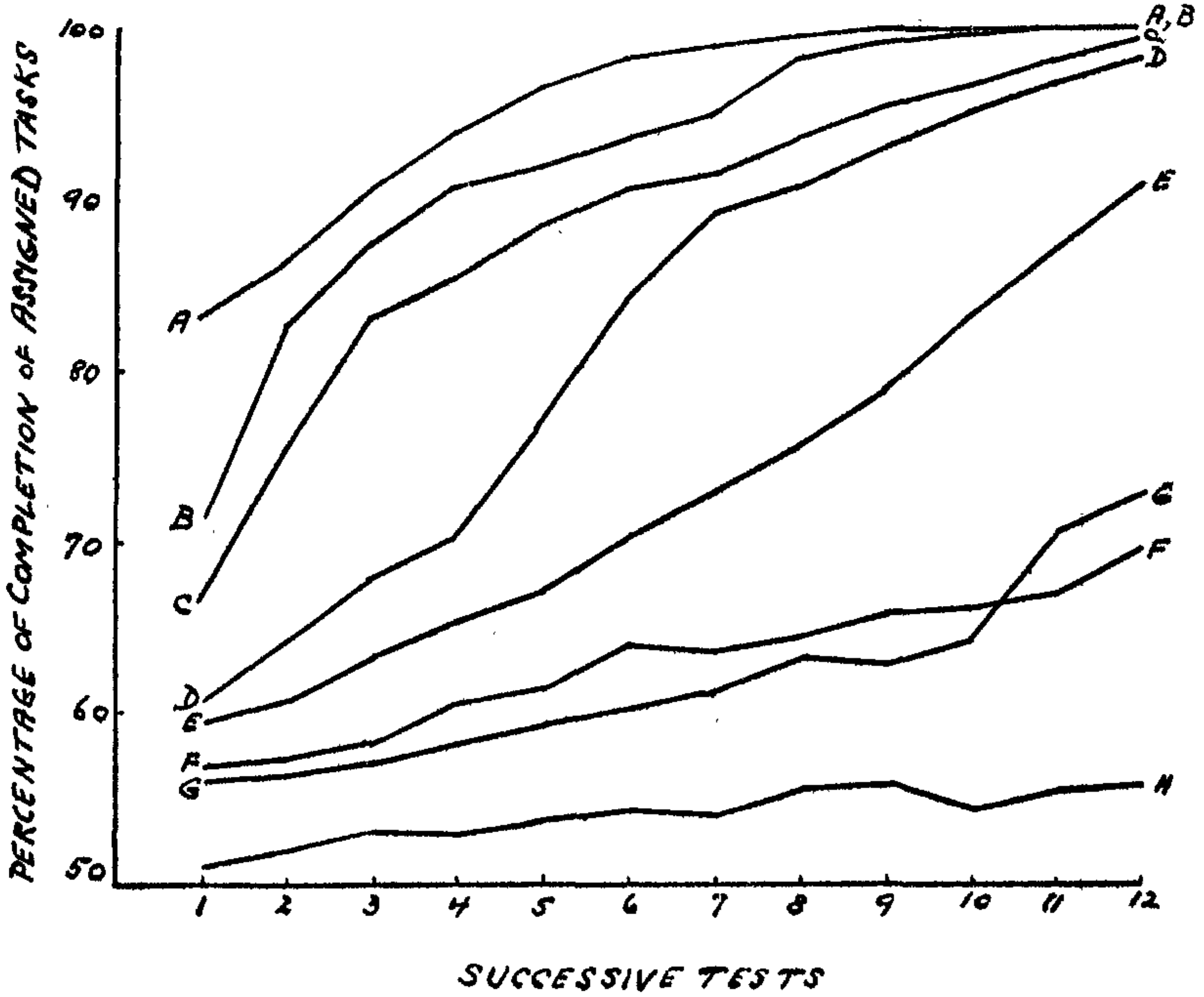
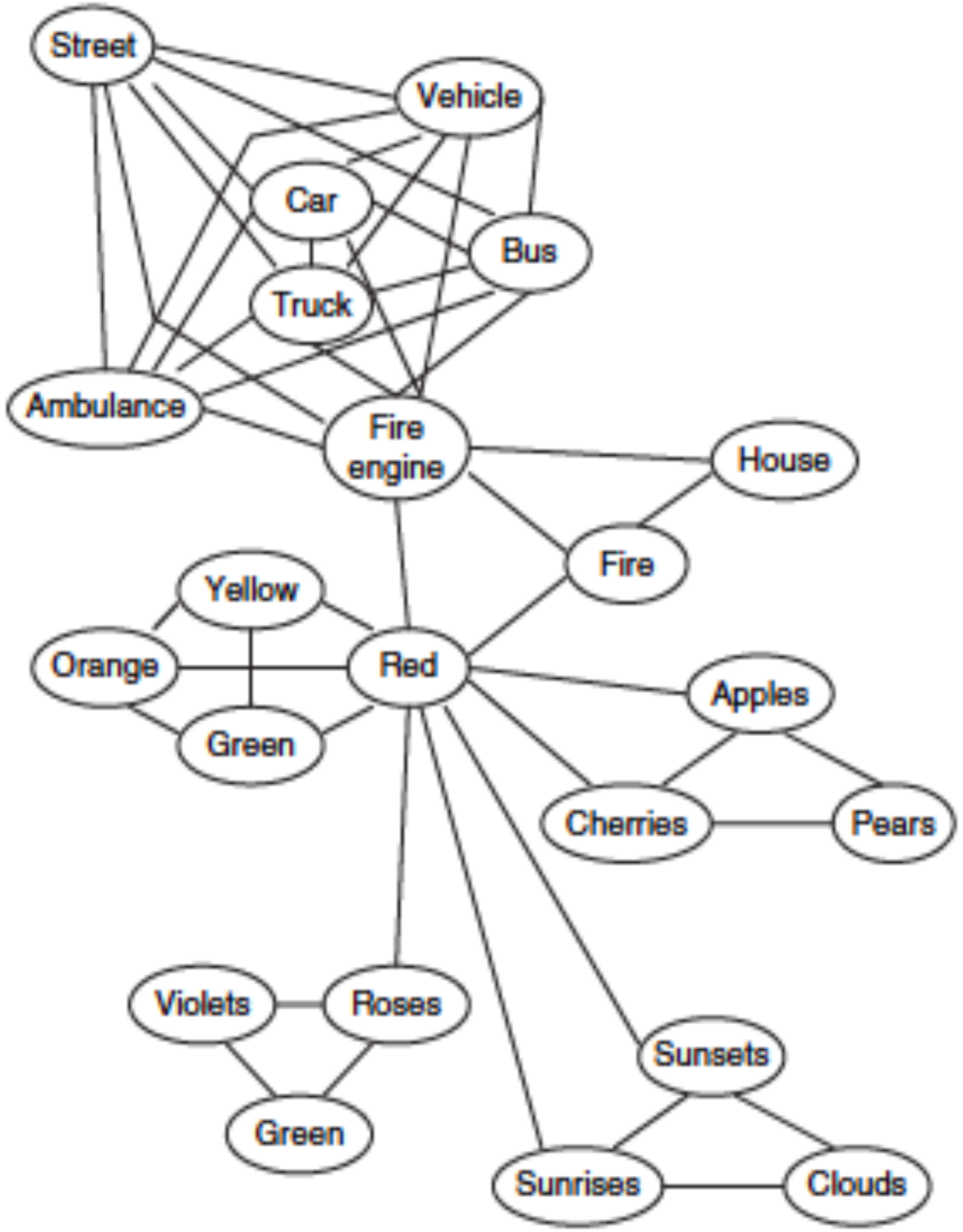


Fig. 1. Curves of Learning Derived from Tasks of Varying Difficulty. Key: (A) Five easy items. (B) Fifteen easy items. (C) Fifty easy items. (D) One hundred easy items. (E) Five difficult items. (F) Fifteen difficult items. (G) Fifty difficult items. (H) One hundred difficult items.

Krueger, 1946

Semantic Network

- Key concept in theories of memory
- Association between related material
- Fire Engine has more links (associations) to vehicle-related nodes
- Weaker links to more general nodes (color, etc.)



Example Substitution Percentage

Group	Hours of simulator study	Hours of operational training required to pass criterion test
1 – Experimental	500	100
2 – Experimental	250	100
3 – Control	0	200

$(Y_c - Y_e)/Y_c$

Y_c = operational time for the control group
Y_{e1} = operational time for experimental groups 1 and 2

200 – 100/200 = ½ = 50%.

- Substitution percentage is same for both groups
- 2nd group program is more effective – less simulator study time for the same reduction in operational time

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Inferring Mental Processes from Manipulations of Stimuli and Variations in Response