Principles of Learning and Instructional Strategies

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Instructional strategies play a central role in the architecture of GIFT (Generalized Intelligent Framework for Tutoring). An adaptive, intelligent, learning environment needs to launch the right instructional strategies at the right time in a mechanism that attempts to be sensitive to the learner model, to maximize learning and motivation, and to minimize training time and costs. Instructional strategies will be the theme of the second advisory board meeting of the collaboration between (1) The Human Research and Engineering Directorate (HRED) of the Army Research Laboratory (ARL) and (2) the Advanced Distributed Learning Center for Intelligent Tutoring Systems Research & Development (ADL CITSRD) in the Institute for Intelligent Systems (IIS) at the University of Memphis. The purpose of this document is to provide a succinct illustration of some instructional strategies and associated principles of learning in order to orient participants at the board meeting.

Instructional strategies have been advocated by researchers and practitioners in many different fields, such as education, educational psychology, cognitive and learning sciences, military training, computer based training, artificial intelligence in education, computer supported collaborative learning, educational data mining -- the list goes on. These fields have different missions so the shared knowledge among members of different fields is unspectacular. The landscape of instructional strategies in one field would not necessarily overlap with the other fields. However, a common ground has been emerging from dozens of reports prepared by interdisciplinary research panels funded by the government and research organizations, particularly during the last decade. Some examples are:

A Roadmap to Educational Technology (2010, National Science Foundation, http://www.cra.org/ccc/docs/groe/GROE Roadmap for Education Technology Final Report.pdf)

The Army Learning Concept for 2015 (2011, United States Army, http://www-tradoc.army.mil/tpubs/pams/tp525-8-2.pdf)

Committee on Science Learning: Computer Games, Simulations, and Education (2011, National Academy of Science, http://www.nap.edu/catalog.php?record_id=13078)

Assessing 21st Century Skills (2011, National Academy of Sciences, http://www.nap.edu/catalog.php?record_id=13215#toc)

Improving Adult Literacy Instruction (2012, National Academy of Sciences, http://www.nap.edu/catalog.php?record_id=13242)

Organizing Instruction and Study to Improve Student Learning (2007, Institute of Education Sciences of the United States Department of Education, http://ies.ed.gov/ncee/wwc/pdf/practice_guides/20072004.pdf)

Lifelong Learning at Work and at Home (2007, American Psychological Association and Association for Psychological Sciences, http://www.psyc.memphis.edu/learning/whatweknow/index.shtml),

The above reports emphasize instructional strategies that are supported by empirical tests with scientific methodologies. Therefore, the strategies are grounded in science and evidence-based rather than the folklore of educational practitioners. Nevertheless, all of the above reports also emphasize practical applications of these strategies. Some reports go to great lengths describing how human teachers can apply particular strategies in teaching practice. Most of these reports describe computer applications that have implemented and tested the strategies. These reports are therefore relevant to GIFT.

Two of these reports illustrate some recommended instructional strategies. *Organizing Instruction and Study to Improve Student Learning* was to serve as a practice guide for teachers. The goal was to focus on a small number of strategies that were backed by science and that could also be reliably applied with the training that teachers typically receive. In other words, the instructional strategies should not be too complex or subtle. The research group identified the following seven principles:

1. Space learning over time.
2. Interleave worked example solutions with problem solving exercises.
3. Combine graphics with verbal descriptions.
4. Connect and integrate abstract and concrete representations of concepts.
5. Use quizzing to promote learning.
6. Help students allocate study time effectively.
7. Ask deep explanatory questions.

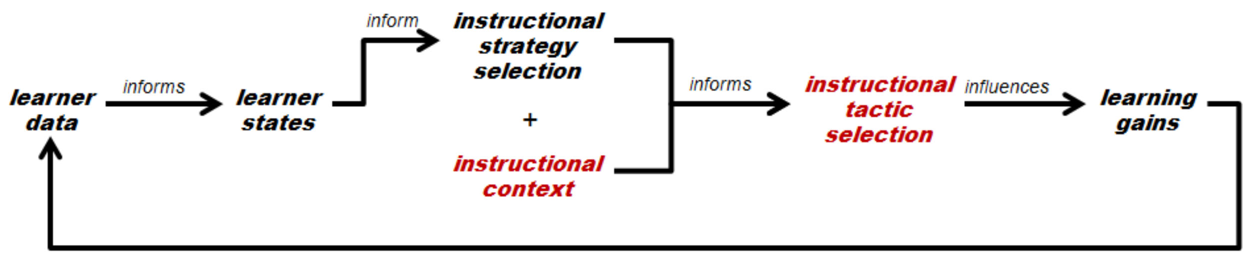
The *Lifelong Learning at Work and at Home* had a larger and more diverse panel of experts, with an eye toward adult learners in addition to K12. These experts generated 25 principles of learning and instructional strategies.

1. Contiguity Effects: Ideas that need to be associated should be presented contiguously in space and time.
2. Perceptual-motor Grounding: Concepts benefit from being grounded in perceptual motor experiences, particularly at early stages of learning.
3. Dual Code and Multimedia Effects: Materials presented in verbal, visual, and multimedia form richer representations than a single medium.
4. Testing Effect: Testing enhances learning, particularly when the tests are aligned with important content.
5. Spacing Effect: Spaced schedules of studying and testing produce better long-term retention than a single study session or test.
6. Exam Expectations: Students benefit more from repeated testing when they expect a final exam.
7. Generation Effect: Learning is enhanced when learners produce answers compared to having them recognize answers.
8. Organization Effects: Outlining, integrating, and synthesizing information produces better learning than rereading materials or other more passive strategies.
9. Coherence Effect: Materials and multimedia should explicitly link related ideas and minimize distracting irrelevant material.
10. Stories and Example Cases: Stories and example cases tend to be remembered better than didactic facts and abstract principles.
11. Multiple Examples: An understanding of an abstract concept improves with multiple and varied examples.

12. Feedback Effects: Students benefit from feedback on their performance in a learning task, but the timing of the feedback depends on the task.
13. Negative Suggestion Effects: Learning wrong information can be reduced when feedback is immediate.
14. Desirable Difficulties: Challenges make learning and retrieval effortful and thereby have positive effects on long-term retention.
15. Manageable Cognitive Load: The information presented to the learner should not overload working memory.
16. Segmentation Principle: A complex lesson should be broken down into manageable subparts.
17. Explanation Effects: Students benefit more from constructing deep coherent explanations (mental models) of the material than memorizing shallow isolated facts.
18. Deep questions: Students benefit more from asking and answering deep questions that elicit explanations (e.g., why, why not, how, what-if) than shallow questions (e.g., who, what, when, where).
19. Cognitive Disequilibrium: Deep reasoning and learning is stimulated by problems that create cognitive disequilibrium, such as obstacles to goals, contradictions, conflict, and anomalies.
20. Cognitive Flexibility: Cognitive flexibility improves with multiple viewpoints that link facts, skills, procedures, and deep conceptual principles.
21. Goldilocks Principle: Assignments should not be too hard or too easy, but at the right level of difficulty for the student's level of skill or prior knowledge.
22. Metacognition: Students rarely have an accurate knowledge of their cognition so their ability to calibrate their comprehension, learning, and memory should not be trusted and they need to be trained to improve important metacognitive judgments.
23. Discovery Learning: Most students have trouble discovering important principles on their own, without careful guidance, scaffolding, or materials with well-crafted affordances.
24. Self-regulated Learning: Most students need training on how to self-regulate their learning and other cognitive processes.
25. Anchored Learning: Learning is deeper and students are more motivated when the materials and skills are anchored in real world problems that matter to the learner.

These lists provide an initial glimpse of instructional strategies, but in a number of ways fall short of providing sufficient guidance for GIFT. The precise conditions in which each strategy should be applied require further specification. Indeed, each strategy is appropriate for some conditions but not others, e.g., distributed over massed practice is typically desirable, but sometimes massed practice is best. There are contradictions or tradeoffs between some of these strategies, e.g., coherence effect versus cognitive disequilibrium. Another shortcoming is that these strategies emphasize cognitive mechanisms at the expense of not giving adequate attention to motivation, emotions, and social interaction. We live in a world where these non-cognitive factors are just as important as cognitive mechanisms.

Within the current GIFT architecture, instructional decisions are divided into strategies and tactics. The current GIFT lexicon defines strategies as domain-independent approaches developed by the pedagogical module and influenced by the learner's states and traits including competence, performance (above expectations, at expectations or below expectations), cognition (engagement, workload), affect (confusion, boredom, frustration), and motivation. Tactics are defined as domain-specific actions based on recommended strategies from the pedagogical module, the instructional context and the learner's states and traits.



Members of the second advisory board were selected because their research fills many of these gaps and provides more sophisticated instructional strategies for GIFT. More specifically, researchers on the board have made major advances in four thematic subcategories: (1) meta-cognition and self-regulated learning, (2) affect, emotions, engagement, and grit, (3) guided instruction and scaffolding, and (4) natural language and discourse. Research in these subcategories is destined to move the horizon of instructional strategies beyond conventional computer-based instruction and onto learning environments with serious games, virtual reality, self-regulation, social interaction, and scaffolding techniques for enhancing both learning and motivation.

As we prepare for the advisory board, we are looking for three key outputs to support the future development of GIFT and other ITS from an instructional strategy perspective:

1. At a macro level, illustrate your vision for how ITS instructional strategies will evolve in the next 5-10 years
2. Identify how your research is focused to contribute to this vision
    a. Identify current strategies for individual and/or team instructional strategy concepts
    b. Identify the conditions under which these strategies would be initiated
    c. Recommend how these strategies can be improved
3. Recommend courses of action for GIFT to support your vision