Metacognition

Effective SRL in Serious Games Emphasizes:

- Metacognition
  - Accurate monitoring and control of learning
  - Flexibility in applying strategies
  - Learning through scaffolding

Metacognition

- Executive processes; oversees the memory system
- Is rather late developing
- Can be improved through direct instruction & modeling
- Is largely independent of general ability

Metacognition

Knowledge of Cognition

Declarative	Procedural	Conditional
Knowledge of memory limitations	Knowledge about Strategies	Knowledge about When and Why to use Strategies

Regulation of Cognition

Planning	Monitoring	Evaluation
Setting goals, Activating Background Knowledge, Budgeting Time	Observation of Performance	Reevaluating Goals, Revising Predictions

Examples of Metacognition

- Knowing how well you are doing on your psychology test
- Predicting how difficult a chemistry project will be
- Understanding how much you know about makes and models of cars
- Knowing what information is important to take away from class lecture
- Knowing how well you can ski

Examples of Metacognition cont.

- Choosing one strategy over another when playing a board game
- Knowing if you have studied enough for the history exam
- Understanding and utilizing strategies that will make you a better setter in volleyball
- Knowing when your performance on the trumpet was up to par
- Knowing which Trivial Pursuit categories you are strong and weak at

Dunning-Kruger Effect

"Unskilled and Unaware"

"Having knowledge is only part of effective learning. It also is important to use one's knowledge strategically and to understand the strengths and limitations of one's knowledge."

(Bruning, Schraw, Ronning, 1999; p. 102)

This is the key distinction between metacognition and cognition.

Effective SRL in Serious Games Emphasizes . . .

. . . accurate monitoring and control of learning.

Monitoring and Calibration

Calibration is the degree to which one can match their *perception* of their performance with their *actual* level of performance.

Calibration is one measure of metacognitive monitoring accuracy

Is calibration related to performance?
Does prior knowledge improve calibration?
Can training and/or feedback improve calibration?

Is calibration related to performance?

TABLE 2. Correlations Among Grade Point Average (GPA), Test Score, and Local Monitoring Accuracy

Test	1	2	3	4	5	6	7	8	9
1 GPA	—	.59**	–.76**	.67**	–.68**	.50**	–.44*	.64**	–.63**
2 Test 1 score		—	–.79**	.59**	–.62**	.63**	–.36**	.64**	–.58**
3 Test 1 accuracy			—	–.63**	.77**	–.60**	.46*	–.69**	.61**
4 Test 2 score				—	–.80**	.40*	–.32	.69**	–.52**
5 Test 2 accuracy					—	–.54**	.48*	–.74**	.69**
6 Test 3 score						—	–.64**	.70**	–.53**
7 Test 3 accuracy								–.36	.69**
8 Test 4 score								—	–.63**
9 Final exam accuracy									—

$^{*}p < .05$. $^{**}p < .01$.

Nietfeld, J. L., Cao, L., & Osborne, J. W. (2005). Metacognitive monitoring accuracy and student performance in the classroom. *Journal of Experimental Education, 74*(1), 7-28.

How many ways can a jury of 4 women and 3 men be chosen from 5 women and 5 men?

A. 20
B. 30
C. 40
D. 50

0%________________________________100%
Accurate Accurate

Does prior knowledge improve calibration?

Design:

- 3 Groups with varied math background
  Low Knowledge N=31
  Mid Knowledge N=34
  High Knowledge N=28
- Completed a test of math probability and general intelligence
- Provided monitoring judgments for each item
- The High Knowledge group significantly outperformed the other two groups ***and*** made significantly more accurate monitoring judgments
- No differences were found in general ability between the 3 groups

Nietfeld, J. L., & Schraw, G. (2002). The role of knowledge and strategy training on metacognitive monitoring. *The Journal of Educational Research, 95*, 131-142.

Can training and/or feedback improve calibration?

Monitoring accuracy on math probability problems by college students – Session 1=pretest, Session 2=after training (for Training group only), Session 3=after one week. Lower numbers equal higher accuracy.

Table 3.—Means and Standard Deviations for Experiment 2

Group	Raven test performance		Probability performance		Probability confidence		Probability bias		Probability accuracy		Self-efficacy	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Training												
Session 1	.64	.23	.58	.12	.70	.13	.14	.15	.37	.09	35.02	8.79
Session 2			.68	.13	.79	.12	.10	.15	.29	.08	33.88	9.01
Session 3			.62	.10	.78	.13	.16	.15	.35	.08	34.07	8.82
Control												
Session 1	.69	.23	.59	.15	.66	.17	.10	.14	.32	.10	36.61	8.93
Session 2			.58	.15	.69	.16	.11	.14	.34	.08	35.79	8.63
Session 3			.60	.09	.69	.16	.09	.16	.36	.08	36.81	9.96

Note. Performance, confidence, and accuracy ranged from 0 to 1. Bias ranged from –1 to 1.

Nietfeld, J. L., & Schraw, G. (2002). The role of knowledge and strategy training on metacognitive monitoring. *The Journal of Educational Research, 95*, 131-142.

Can training and/or feedback improve calibration?

No change in monitoring accuracy (calibration) in the absence of training or feedback.

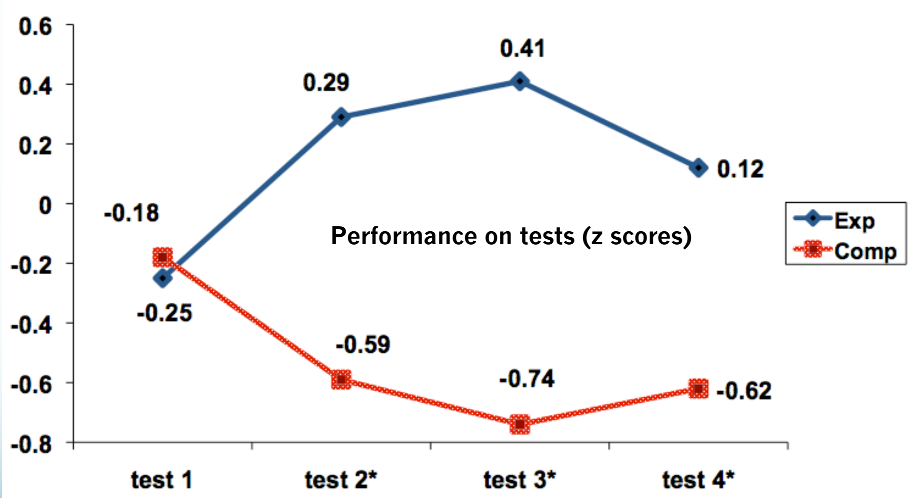
TABLE 1. Means and Standard Deviations of Monitoring Accuracy, Bias, and Confidence, by Test

			Monitoring accuracy								
	Score		Local		Global		Bias		Confidence		
Item	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*n*
Test 1	.78	.13	.29	.11	.13	.10	−.03	.11	.75	.13	27
Test 2	.81	.09	.29	.10	.13	.12	−.05	.12	.76	.13	27
Test 3	.76	.13	.35	.12	.26	.18	−.07	.19	.68	.18	27
Final	.81	.12	.28	.11	.11	.11	−.02	.17	.78	.16	26
GPA	3.35	.41									27

Note. GPA = grade point average.

Nietfeld, J. L., Cao, L., & Osborne, J. W. (2005). Metacognitive monitoring accuracy and student performance in the classroom. *Journal of Experimental Education, 74*(1), 7-28.

Can training and/or feedback improve calibration?



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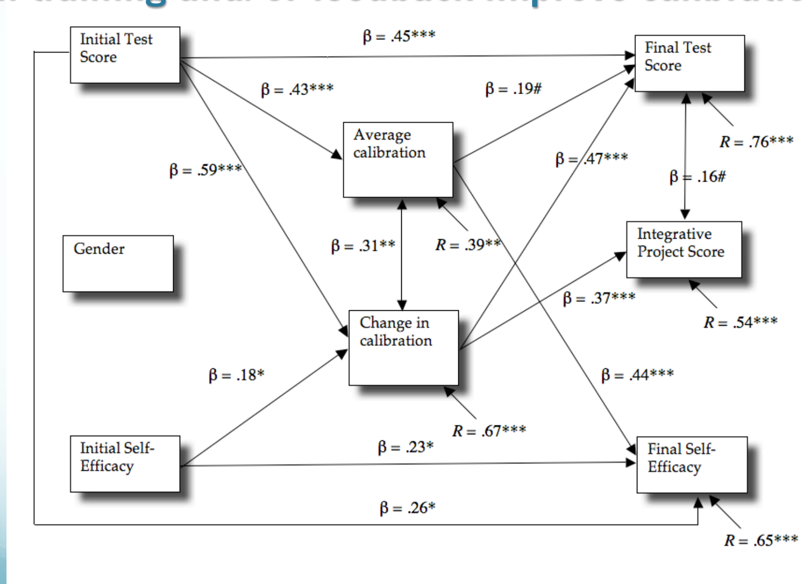


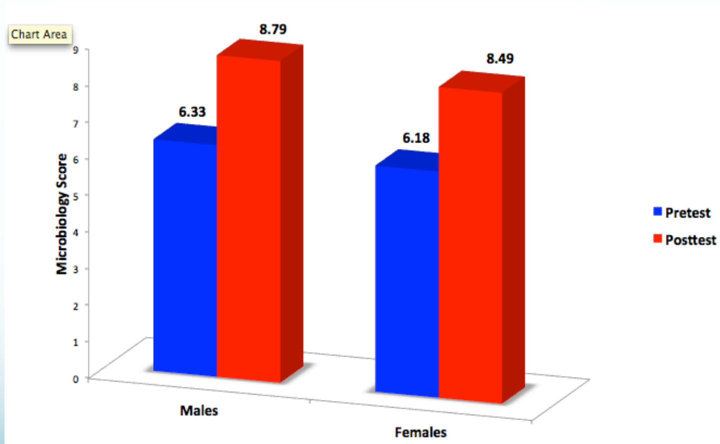
Nietfeld, J. L., Cao, L., & Osborne, J. W. (2006). The effect of distributed monitoring exercises and feedback on performance and monitoring accuracy. *Metacognition and Learning, 2,* 159-179.

Crystal Island - Outbreak Research Team

- Interdisciplinary Coordination
  - Computer Science
  - Educational Psychology
  - Curriculum & Instruction
  - K-12 students and teachers
- Infrastructure
  - Computational: Game Technology
  - Personnel: Graphic Design & Animation

Results

What is the impact of gender on performance in CRYSTAL ISLAND?



Both genders made significant increases in content knowledge but no differences between gender

What is the impact of playing CRYSTAL ISLAND on learning?

- Prior knowledge and goals completed were significant predictors of posttest content knowledge
- Controlling for prior knowledge found students who completed the CRYSTAL ISLAND - OUTBREAK mystery scored significantly higher on:
  - microbiology post-test
  - presence
  - situational interest
  - self-efficacy for science
  - diagnosis worksheet total
  - performance on transfer tasks

Table 3

Regression Results Predicting Performance in Crystal Island–Outbreak

Predictors	*B*	*SE*	β
Constant	−550.24	235.37	
Diagnosis worksheet use	10.48	2.31	.36***
Interest	9.97	3.66	.20**
Self-Efficacy for science	16.95	6.14	.22**
Monitoring bias	−355.37	103.93	−.26**
Prior knowledge	33.33	15.96	.16*
Perceived game skill	−20.11	25.09	−.06
Mastery approach	−16.02	10.15	−.12
Performance approach	3.45	6.74	.04
R^2		.420	

Note. Dependent variable is performance in Crystal Island–Outbreak. *SE* = standard error.
* $p < .05$. ** $p < .01$. *** $p < .001$.

Nietfeld, J. L., Shores, L. R., & Hoffmann, K. F. (2014). Self-regulation and gender within a game-based learning environment, *Journal of Educational Psychology*, *106*, 961-973.

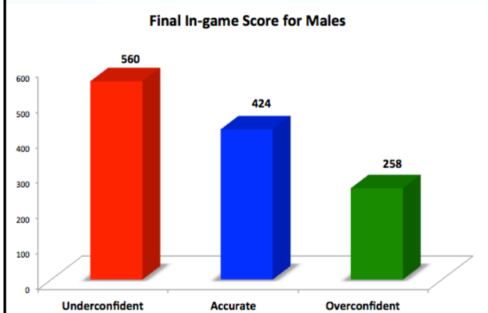
Results

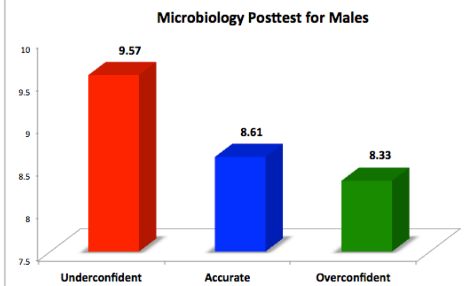
What is the impact of gender on performance in CRYSTAL ISLAND?

- **During gameplay, males completed significantly more goals than females although these group differences disappear when controlling for number of reported hours playing video games.**
- **Our findings suggest that males and females may be motivated to perform well in environments such as CRYSTAL ISLAND for different reasons and may regulate their performance differently to achieve similar outcomes.**
- **Predicting female performance was more elusive than male performance in our setting**

Results

The impact of overconfidence with males:





Crystal Island: Uncharted Discovery

Overall Problem: Establishing Village Life

Quest 1: Landform Identification	Quest 2: Map Navigation	Quest 3: Modeling
Level 1	**Level 1**	**Level 1**
The geographer asks the student to label three landforms (waterfall, dam, plateau).	The student is asked to navigate to three locations on the island using map coordinates and to pick up a flag at each location. The student can only carry three flags at a time. Flags can be picked up and dropped anywhere. Decoy flags are also present.	The student is asked to match a photo of the island with a model meant to represent that part of the island.
Level 2	**Level 2**	**Level 2**
The geographer asks the student to photograph three landforms (lake, delta, and tributary) that are identified on her blackboard by definition only. For example, the student would have to know that "a stream or river that flows into another river" is a tributary.	The student is asked to navigate to three locations on the island using compass points, map coordinates, and a map scale. The student must then take a picture of an animal at each location. Decoy animals are also present.	The student is asked to create a virtual model of the village. The cartographer gives the student an app for the virtual tablet that allows the student to arrange the hut models into the correct configuration.

What SRL variables predict performance in CRYSTAL ISLAND – UNCHARTED DISCOVERY ?

If Calibration is replaced by response bias R^2 increases to .62

Note: Mastery Approach and Strategies Attribution were significant if using $p < .10$

Regression Results Predicting Efficiency in

CRYSTAL ISLAND - UNCHARTED DISCOVERY

Predictors	B	SE	β
Constant	2548.65	868.18	
Calibration	2504.64	465.14	.39***
Treasure Chest Time	2.85	.79	.25***
Interest	-379.37	115.05	-.24**
Luck Attribution	186.28	70.85	.19*
Mastery Approach	151.04	79.99	.16
Strategies Attribution	-191.25	105.60	-.14
Map Access	-22.87	19.41	-.09
Prior Knowledge	-34.52	30.26	-.09
Effort Attribution	-87.46	118.90	-.06
Performance Approach	-21.00	40.48	-.04
Science Self-Efficacy	91.88	200.69	.04
R^2		.521	

Note.

*$p < .05$, ** $p < .01$. *** $p < .001$.

Some General Conclusions:

✓ It appears that monitoring accuracy (calibration) is not strongly related to general ability, perhaps not related at all

✓ Background knowledge (at least within the domain of probability) appears to be an essential component in the development of accurate monitoring skills

✓ Strategy training appears to be an effective means by which to increase skill ***and*** monitoring accuracy

✓ Distributed strategy training over time appears to be necessary to ensure the maintenance of gains in monitoring accuracy

Implications for Serious Games:

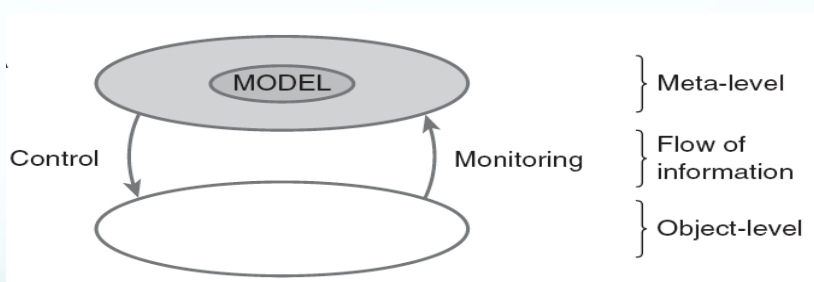
✓ Monitoring accuracy can be measured via traditional content-based items or in judgments related to the completion of quests

✓Monitoring accuracy may predict in game performance and efficiency at higher levels than even prior knowledge

Effective SRL in Serious Games Emphasizes . . .

. . . flexibility in applying strategies.

The "Knowing" and "Adjusting" Processes:



Adapted from Nelson & Narens (1990)

A Good Strategy User . . .

- Has a broad repertoire of strategies
- Metacognitive knowledge about why, when, and where to use strategies
- Has a broad knowledge base
- Ignores distractions
- Is automatic in the four components described above

Pressley, Borkowski, and Schneider (1987)

A Self-Regulatory Approach to Study Strategies:

- Self-Checking
- Creating a productive physical environment
- Goal setting and planning
- Reviewing and organizing information after learning
- Summarizing during learning
- Seeking assistance
- Determining how much information to learn

A Self-Regulatory Approach to Study Strategies:

- Determining how new information relates to existing knowledge
- Determining how information will be used
- Identifying main ideas and important information
- Predicting
- Monitoring
- Reflecting on previous learning

3 Levels of Cognitive Study Strategies

- **Basic Study Strategies**
  - Highlighting/Underlining/Note Taking
  - Don't take for granted that students know these!
- **Comprehension Monitoring Strategies**
  - Self-questioning/Summarizing
  - These are things you do "on-line" while learning
- **Critical Thinking**
  - Most important level--this is your goal!
  - What is critical thinking?

Ten Essential Critical Thinking Skills

- Distinguishing between verifiable facts and value claims
- Distinguishing between relevant and irrelevant information, claims, or reasons
- Determining the factual accuracy of a statement
- Determining the credibility of a source
- Identifying ambiguous claims or arguments

Ten Essential Critical Thinking Skills cont.

- Identifying unstated assumptions
- Detecting bias
- Identifying logical fallacies
- Recognizing logical inconsistencies in a line of reasoning
- Determining the strength of an argument or claim

Taken from Beyer (1988)

Teaching Metacognitive Strategy Regulation

- Model strategies that cut across domains
- Encourage students to transfer strategies (eliminate inert knowledge)
- Demonstrate why some strategies are better than others
- Explain when and where a strategy will be used
- Use checklists to help monitor

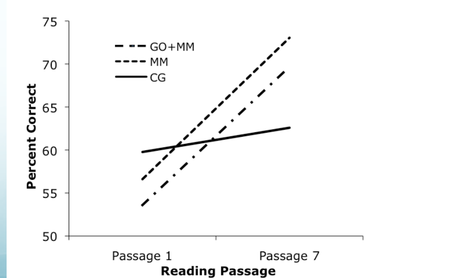
Give metacognitive strategy instruction a chance to "sink in" . . .

Study in how 5th graders comprehend expository science text

In 4 conditions:
1) Graphic organizer + Metacognitive instruction
2) Metacognitive instruction
3) Graphic Organizer instruction
4) Traditional instruction

After 6 weeks an effect is found

Comprehension Score Change over Time, Controlling for Prior Knowledge

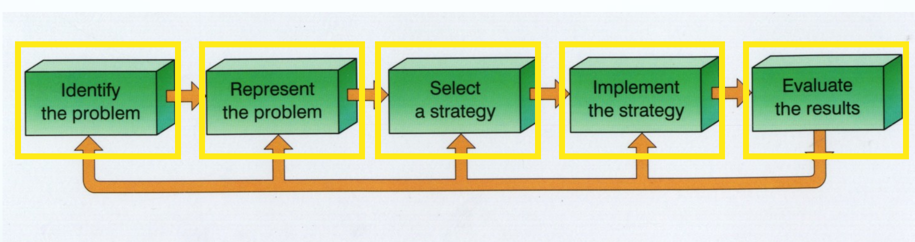


Hoffmann, K. F. (2010, dissertation)

Implications for Serious Games:

- Above all, help learners to learn to be strategic. This includes helping them to learn many strategies and be flexible in using them
- Also, keep in mind that strategies are only effective when learners know when, where, and why they should apply them
- Consider including tools that encourage learners to make a habit of actively reflecting on their learning

General Problem-Solving Model



Identifying the Problem:

- People are not in the habit of problem finding
- Enough background knowledge?
- People tend to be impulsive and not reflect on the nature of the problem
- Well-Defined vs. Ill-Defined

Well versus Ill-Defined

Ill-Defined

- Desired goal unclear
- Information missing
- Several possible solutions

Well-Defined

- Goal clearly stated
- All information present
- Only one correct solution

Representing the Problem:

- Consider external representations to relieve demands upon working memory and organize information (e.g. pictures, diagrams, charts)
- Experts spend proportionately more time at this stage than novices

Selecting Strategies:

Algorithm

- Exhaustive
- Solution guaranteed

Heuristic

- Rules-of-thumb
- Efficient
- Solution not guaranteed
- Examples
  - *Trial & Error*
  - *Means End Analysis*
  - *Analogy*
  - *Working Backwards*

Implementing the Strategy:

- Experts utilize more strategies (strategy shifting), consider more solutions, and evaluate solutions at a deeper level
- Convergent vs. Divergent thinking

Convergent Thinking

Focus on one solution

Divergent Thinking

Consider novel solutions

What is Creativity?

"Ability to produce work that is both novel and appropriate"
(Sternberg & Lubart, 1996)

"The capacity to perform mental work that leads to an outcome both novel and applicable." (Pereira, 1999)

NOVEL -> original, unexpected

- => **Associative thinking – recombine existing knowledge with divergent approaches**

PRODUCTIVE -> appropriate, applicable, useful, meets task constraints, has a contribution

- => **Critical thinking – What you select out, focus on**

Creativity & Metacognition

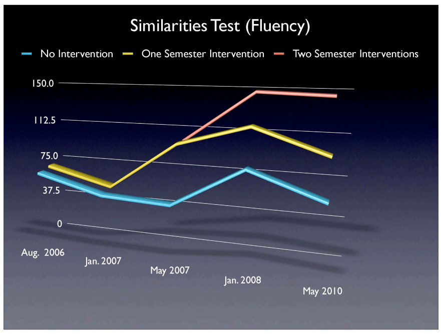
Figure 4: Students Working In The Design Studio

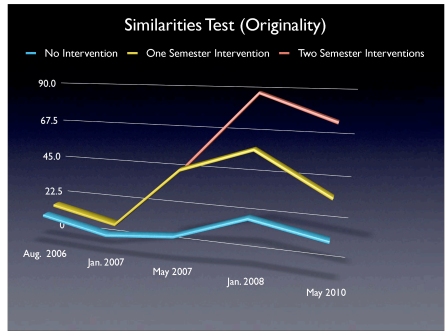
Lead Investigator: Ryan Hargrove, PhD., University of Kentucky

Schedule for the Semester

Class 1: Activity
Introduction
Discussion of class purpose and objectives
Class 2: Introduction to creative strategies
Creative Strategy 1 – Brainstorming / Reverse Brainstorming
Framework for effective metacognitive practices
Class 3: Lateral Thinking Lesson
Knowledge of cognition
Class 4: Creative Strategy 2 – Random Input
Regulation of cognition
Class 5: Creative Strategy 3 – Analogy Technique / Forced Analogy / Mind Mapping
Cycle of knowledge and regulation of cognition
Class 6: Creative Strategy 4 – Metaphorical Thinking
Key operations of metacognition
Class 7: Synectics Lesson
Importance of practice
Class 8: Creative Strategy 5 – The Discontinuity Principle
Conceptual level
Class 9: Creative Strategy 6 – Storyboarding
Rubric for self-assessment
-----------------------SELF-ASSESSMENT -------------------------------
Class 10: Creative Strategy 7 – Lotus Blossom Technique
Metacognitive Facet 1 - Explanation Class 11: Creative Strategy 8 – Assumption Smashing
Metacognitive Facet 2 - Interpretation
Class 12: Creative Strategy 9 – Escapism Technique
Metacognitive Facet 3 - Application
Class 13: Creative Strategy 10 – Search and Reapply Technique
Metacognitive Facet 4 - Perspective
Class 14: Creative Strategy 11 – Idea Checklist / SCAMPER
Metacognitive Facet 5 - Empathy
Class 15: Creative Strategy 12 – Attribute Listing / Morphological Charts / Morphological Forced Connections
Metacognitive Facet 6 – Self-Knowledge
Class 16: Conclusion and Wrap-up

Creativity & Metacognition





Hargrove, R. A., & Nietfeld, J. L. (2014). The impact of metacognitive instruction on creative problem solving. *Journal of Experimental Education*. DOI: 10.1080/00220973.2013.876604

Physics Playground

- Game that emphasizes 2D physics simulations – gravity, mass, kinetic energy, & transfer of momentum
- Objective is to guide a green ball to a red balloon(s)
- Primary way to get the ball to move is to draw objects that "come to life" – with all movement obeying Newton's three laws of motion

Fostering Creativity

- Show students that creativity is valued
- Focus on internal rewards
- Promote mastery of subject area
- Ask thought-provoking questions
- Encourage metacognitive strategies that support creative thinking
- Give students freedom, security to take risks

Functional Fixedness

A condition that arises when we lose the ability to view familiar objects in a novel way

Evaluating the Results:

- The chance to improve problem-solving skills rests at this stage and is very metacognitive in nature
- Teachers who are "reflective practitioners" spend more time at this stage
- The development of self-regulatory skills is dependent upon evaluation

Transfer of Learning

- Occurs when something learned at one time and place is applied in another setting
  - Transferring to another university
    - Schedule time with advisor
    - Knowing how to register for classes
    - Where to find information--library
- Most difficult challenge for teachers!
- People often don't realize the relevance of their prior knowledge in new situations
- Important to instill a "disposition for transfer" in your learners
- Need to reduce inert knowledge

Factors Affecting Transfer

- Structured practice that promotes **automated** problem solving increases transfer
- **Meaningful learning** leads to greater transfer than rote learning
- Relate problem-solving skills in one domain to another by the use of **analogy**. Students should see material as context-free rather than context-bound
- Give numerous worked-out **examples**
- **Similarity** between two situations increases transfer
- Transfer is more likely when only a **short amount of time** has elapsed after students have studied a topic

Crystal Island: Uncharted Discovery

Final Inquiry Project

Goal for Inquiry Project

- Assess students' ability to identify landforms and display an understanding of map navigation and map models outside of CRYSTAL ISLAND

Implications for Serious Games:

- Effective learners are flexible problem solvers, they toggle between strategies, and think divergently/creatively
- Consider tools to help learners representing problems
- Promote general strategies (e.g. draw out the problem, take your time, consider many different strategies to solve the problem, utilize background knowledge)
- Always focus on transfer outside the game

Effective SRL in Games Emphasizes . . .

. . . learning through scaffolding

Vygotsky's Social Constructivism

Zone of Proximal Development

"the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers."

Vygotsky, 1935

Regression Results Predicting Performance in Crystal Island–Outbreak

Predictors	*B*	*SE*	β
Constant	−550.24	235.37	
Diagnosis worksheet use	10.48	2.31	.36***
Interest	9.97	3.66	.20**
Self-Efficacy for science	16.95	6.14	.22**
Monitoring bias	−355.37	103.93	−.26**
Prior knowledge	33.33	15.96	.16*
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Note. Dependent variable is performance in Crystal Island–Outbreak. *SE* = standard error.
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Table 1

Differences in learning gains divided by diagnosis worksheet performance and prior knowledge differences

Measure	Low Worksheet Score *N* = 59		High Worksheet Score *N* = 78	
	Low Prior Knowledge *N* = 38	High Prior Knowledge *N* = 21	Low Prior Knowledge *N* = 32	High Prior Knowledge *N* = 46
Microbiology Pre-Test	4.50 (1.31)**	7.86 (0.85)**	5.12 (1.04)**	8.13 (2.48)**
Microbiology Post-Test	6.68 (2.39)**	8.95 (2.78)**	9.09 (2.82)	10.04 (2.48)
Application-Level Content Pre-Test	2.25 (1.20)**	4.43 (1.21)**	2.43 (1.04)**	3.98 (1.14)**
Application-Level Content Post-Test	3.42 (1.38)**	4.62 (1.80)**	4.17 (1.80)	4.81 (1.35)
Fact-Level Content Pre-Test	2.39 (1.32)**	3.43 (0.87)**	2.67 (0.99)**	4.09 (1.06)**
Fact-Level Content Post-Test	3.17 (1.65)*	4.33 (2.00)*	4.97 (1.45)	5.21 (1.67)

Note: ** - $p < .01$, * - $p < .05$

Narrative-Centered Learning Environments

- Game-based learning environments in which learners:
  - Actively participate in “story-centric” problem-solving activities (Rowe, Shores, Mott, & Lester, 2010)
  - Immersed in captivating, highly tailored narratives
- Revolve around:
  - Believable characters
  - Compelling virtual worlds
  - Rich stories

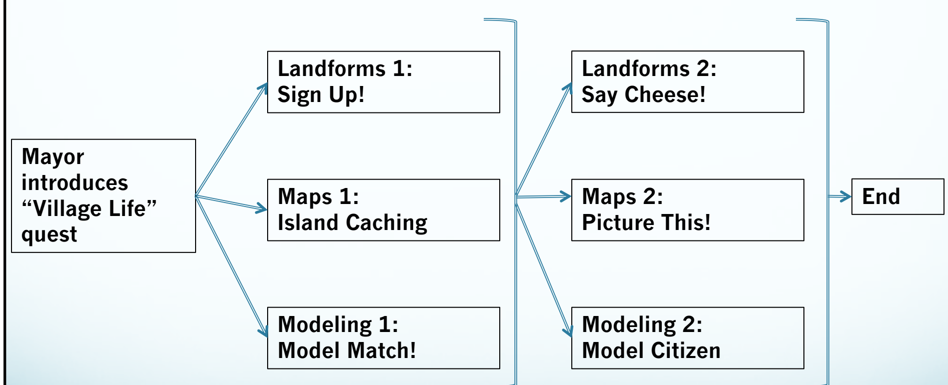
Crystal Island: Uncharted Discovery

- Aligned with the NC 5th grade Standard Course of Study
  - Landform identification
  - Map skills (map interpretation, models)
  - Problem-solving skills
- Overall objective: shipwrecked crew must establish life on volcanic island
- Access to several resources
  - Experts– cartographer, geographer
  - Tablet– island map, IslandPedia, quest log, camera, problem-solving model

Crystal Island: Uncharted Discovery

- 6 "quests": short, manageable tasks focused on one aspect of the curriculum
  - 3 sub-quests, 2 levels each
    1. Landform Identification
    2. Map Navigation
    3. Modeling
- Levels indicate difficulty
- Can be played simultaneously
- Must finish level 1 before unlocking level 2

Crystal Island: Uncharted Discovery



Some things we know about problem solving in Crystal Island – Uncharted Discovery . . .

- Girls solve quests and learn content knowledge at similar rates to boys
- Ability to accurately predict performance (calibration) is a significant predictor of game play efficiency
- Time spent on “seductive” activities is negatively correlated with both game and content performance
- Problem-solving apps haven’t helped in the short term studies

Journal of Educational Psychology
2012, Vol. 104, No. 4, 1074–1082

0022-0663/12/$12.00 DOI: 10.10

Paper-Based Aids for Learning With a Computer-Based Game

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The purpose of this study was to test the instructional value of adding paper-based metacognitive prompting features to a gamelike environment for learning about electrical circuits, called the Circuit Game. In Experiment 1, students who were prompted during Levels 1 through 9 to direct their attention to the most relevant features of the game and were provided with a list of its underlying principles to relate to their game actions performed better on an embedded transfer test (i.e., Level 10) than those not provided with the intervention ($d = 0.77$). In Experiment 2, the principles were not explicitly provided; instead, students were asked to fill in the correct features of each principle on a sheet while playing Levels 1 through 9 of the game. Results indicated that this method of prompting improved transfer performance only for learners who could correctly fill in the list of the game’s principles ($d = 0.53$). Overall, paper-based aids for directing students’ attention toward the most relevant features of a game and asking them to apply provided principles to solve game-based problems result in a deeper understanding of the game’s academic content.

Keywords: educational games, metacognition, multimedia learning