The Neurophysiology of Learning and Memory

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Argument

To understand how games work, they must be studied independently of other disciplines.

We must then develop operational definitions that map to other disciplines, particularly the Learning Sciences.

If we do not align GBL with the Learning Sciences, GBL will be a short-lived endeavor.

1. Each game is an experiment.
2. Our experiments need to be grounded in theory.
3. Falsifiable experiments need to be conducted to refine theory.
4. Design-based experiments need to be conducted to see if experiments generalize to classrooms.
Rebuttal

“Fascist! Reductionist! Art escapes all definition!”
Counter Rebuttal

It’s already happened. Game designers and developers have a language to describe their craft, and they develop new operational definitions as needed.

Someone just needs to take care of the mapping.
Counter-Counter Rebuttal

A creative act is only creative once!

Previous success can’t predict future outcomes!
Creativity is a process that results in content.

Content may only be considered original once.

However, the process can be repeated ad infinitum.

Not necessarily…

J.S. Bach
- Procedural Generator

I ♡ Science
Let’s mix it up

Game-Based Learning Principles

- Learning Science
- Pedagogy
- Game Mechanics
Game-Based Learning
Principles and Practices
Version 1.0
GBL Principle 1

Learning is ultimately a physiological process. Read as much as you can about perception, attention, learning, memory, reasoning, and motivation.
Our senses are bombarded with data

Attention is used to gate information processing

To process the visual array with equal resolution would require enormous heads (and birth canals)
Selective Attention

(b)

Time 1

Time 2

Time 3

This cue is valid.

Endogenous cue - comes from within
Exogenous cue - comes from the environment
(e.g., ambulance siren)
Attentional Blink

- Letter on, 15 ms
- Letter off, 85 ms
- First target in white (T1; position 0)
- Between 7 and 15 random letters
- 8 random letters: 50% of the time, one is an X
- Position 1 (after T1)
- Position 2 (after T1)
- T1
- T2
Attentional Blink
Perceptual “Filling In”

- There is a blind spot in the visual field corresponding to the optic disk.
- The brain uses available evidence to “fill in” for missing input.
Decision Making

- Prospect Theory (Tversky & Kahneman, 1979)
- Utility = prob × value
- We make errors when dealing with rare outcomes
- Activity in anterior cingulate cortex correlates with perceived utility

GBL Principle 2

Recognize key differences in cognition between age groups and other populations.
Know your audience

• Individual differences are critical
• One size does not fit all
• Understand unique needs of your learners
• Games provide opportunities for individualized learning
Development of Executive Function

Source: Paul Thompson, UCLA
GBL Principle 3a

Identify the desired learning outcomes. Reconcile these outcomes with standard pedagogy and accepted methods of assessment.
Operational Definitions

Learning and memory are theoretical concepts that cannot be directly measured.

Independent Variables
- Operational definitions informed by learning outcomes

Black Box

Dependent Variables
- Learning outcomes
- Derived from accepted methods and/or standard assessments
GBL Principle 3b

Distinguish processes (e.g., critical thinking) from content (e.g., the historic journey of Lewis and Clark).
Multiple Memory Systems

Episodic Memory
- Largely for events
- Supported by hippocampus, subiculum, entorhinal cortex, perirhinal cortex & parahippocampus cortex

Semantic Memory
- Largely for facts
- Supported by entorhinal cortex, perirhinal cortex & parahippocampus cortex

Düzel et al. (1999) PNAS. 96(4)-1794-1799
GBL Principle 4

Become an advocate for the player. The game is a vehicle to create an experience in the player’s mind. You are the architect of that experience.
Influencing Mental Models

- The retina and brain process an unfathomable amount of data to create a 3-D representation of the world from the 2-D retinal image.
- Games create opportunities for the player to “fill in.”
- Players fill in for missing/impoverished data.
- Unsolved problems are presented to players.
- Solutions to problems update the mental model.

GBL Principle 5

Develop a core game mechanic that directly supports learning outcomes. Ideally, the core mechanic and the in-game pedagogy are identical.
Avoid “Chocolate Covered Broccoli”

- Core game mechanic is the most prevalent or most important behavior in the game
- The core mechanic must be wedded to the behaviors you are trying to shape with your pedagogy
- Otherwise, the game mechanic might overshadow the pedagogy
Intrinsic vs. Extrinsic Rewards

- Reward is signaled in the brain by the delivery of dopamine to the nucleus accumbens, which strengthens neural connections between stimuli and responses.
- Extrinsic rewards like money can devalue intrinsic rewards.
- Secondary reinforcers take on the value of primary reinforcers.
- How do you get a musician to complain? Get her a gig.
Create game objectives that coincide with the learning outcomes
Successive Approximations

- You can have several learning objectives
- These may occur in stages
- By *scaffolding* the stages of learning, you might achieve your final learning outcome
- We learn more when we can attach new knowledge to existing schemas
- Spaced learning or distributed learning maximizes retention
GBL Principle 7

Use *flow* to sustain engagement until players achieve the learning outcomes
Yerkes-Dodson Law

![Graph showing the Yerkes-Dodson Law](image)

- **Optimal arousal**
- **Optimal performance**
- **Impaired performance because of strong anxiety**
- **Increasing attention and interest**

- **Performance**
  - Strong
  - Weak

- **Arousal**
  - Low
  - High
Reticular Activating System

Mediates Sleep-Wake Cycle
HPA-Axis Supports Stress

HPA Axis

- Hypothalamus
  - CRH
  - Corticotropin Releasing Hormone

- Anterior Pituitary
  - ACTH
  - Adrenocorticotropic Hormone

- Adrenal Cortex
  - CORT
  - Cortisol

Negative Feedback
GBL Principle 8

Use Applied Behavior Analysis (ABA) to shape desirable behaviors
Operant Conditioning

- **Reward** – supported by the nucleus accumbens
- **Punishment** – supported in part by neural circuits for stress
- **Timing** between stimulus, response, and reward also mediated by the interpositus nucleus of the cerebellum
Reward Schedules

- **Fixed ratio**
- **Variable ratio**
- **Fixed interval**
- **Variable interval**
- **Rapid responding near time for reinforcement**
- **Steady responding**
GBL Principle 9

Adjust task difficulty according to performance using classic psychophysical staircase procedures
1-up/1-down Staircase Method
GBL Principle 10

Embed your method of assessment into the game
In-Game Assessment

1. Saves time

2. Can be used to adjust difficulty to each individual’s need

3. Can be compared to post-game assessments
   a. Determine reliability
   b. Determine generalizability of learning

http://glasslabgames.org/research/
GBL Principle 11

Provide short- and long-term feedback regarding performance
1. Short-term feedback lets the user know how to behave

2. Keeps users in a state of flow and sustains engagement

3. Immediate reinforcement stimulates neural circuits for motivation

4. Simulation enhances vigilance

“Juice it or loose it”

Long-term Feedback

1. Serves the learning outcomes
2. Serves the game objective(s)
3. Sustains motivation
4. Inventories spare working memory. The player can focus on the main task.
5. Compound schedules can use ST and LT feedback to support complicated behaviors
GBL Principle 12

Identify and repurpose established game mechanics, resources, and vocabulary whenever possible. Learning is easiest when we introduce subtle changes to existing schemas.
Attach New Learning to Old Schemas

**PTSD.**
Disabling anxiety, nightmares, or flashbacks after a traumatic event.

* +1 Card
* +2 Actions

$2

**Exposure.**
Facing your phobia by desensitizing yourself to the situation.

* +2 Copper
* +1 Buy Helps Specific Phobias, Social Anxiety, Agoraphobia, and Panic Attacks

$1
GBL Principle 13

Identify the formal elements of your genre, including the number of players, objectives, procedures, rules, resources, conflict, boundaries and outcomes.
Boundaries
Boundaries
QWOP is only fun because it messes with automatic processes in the Basal Ganglia
Basal Ganglia

- Striatum
  - Caudate nucleus
  - Putamen
- Globus pallidus
- Subthalamic nucleus
- Substantia nigra
GBL Principle 14

Create system dynamics and game economies that appropriately support the learning outcomes
Resource Management in SimCityEdu
Machination is a Computer Model
GBL Principle 15

Develop dramatic elements that sustain engagement without contradicting or obfuscating the learning outcomes. Identify the game genre, narrative style, voice (i.e., first person, second person, 3rd person omniscient), metaphors, characters, story, aesthetics, and dramatic story arc.
Chess
No wait... Chess
Oh yeah... Chess
GBL Principle 16

Use an iterative approach to game development (e.g., brainstorming, refinement, paper prototyping, digital prototyping, Q & A, and play-testing).
SCORM

Vision

Iteration 1

Iteration 2

Iteration 3

Iteration 4

Continue

Iteration Detail

Implementation & Developer Testing

Design & Analysis

Detailed Requirements

Evaluation / Prioritization

QA / Acceptance Testing

(Deployment)

http://scrumreferencecard.com
GBL Principle 17

Be weary of *fun killers* including trivial challenges, insurmountable challenges, lack of novelty, and arbitrary consequences for actions.
Resources

Contact

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