# RADAR: A Mnemonics-Based Framework for Designing Educational Serious Games for Retrieval Practice

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**Abstract**

Research shows that retrieval practice is more likely to promote learning than repeated study, with mnemonics-based educational serious games (MESGs) that support retrieval practice beginning to gain traction in education. However, there is no available framework to help guide the development of MESGs aimed at motivating retrieval practice. Hence, we proposed a novel framework called "RADAR" focused on life-long learning to help educators and developers implement effective MESGs. Just like a radar system uses shortwaves to detect an out-of-sight object, the RADAR framework uses mnemonics to keep out-of-memory information on "learners' radar" to facilitate easy and quick retrieval when needed. RADAR (**R**ecollection, **A**ssociation, **D**ecoding and **A**rtifacts **R**eview) refers to the four key cognitive stages of a MESG aimed at motivating rehearsal and recollection of learned information in memory-intensive courses. Recollection tests the player's ability to recall or recognize their created mnemonics, which include acronyms and acrostics. Association tests the player's ability to link each recollected mnemonic to its corresponding topic. Decoding tests the player's ability to decipher the meaning of the mnemonic letter by letter or word by word. Finally, Artifacts Review enables the player to review and reflect on the mnemonic artifacts including the mnemonic itself, its visual representation, target and other related information to reinforce their knowledge. A RADAR-based game was validated in a biology-content study, in which the experimental group ($n$ = 30) performed significantly better than the control group ($n$ = 22) that used rote memorization to learn the content. This finding suggests that RADAR-based games can be used by instructors and students to support traditional learning strategies in memory-intensive courses such as biology and psychology.

**Keywords**

Mnemonic, cognitive cue, memory, educational tool, serious game, motivation, persuasive design, RADAR

## 1. Introduction

Many courses in natural science, social science, and humanities that require memorization are becoming more challenging for many higher education students, especially with the ever-increasing volume of textbooks and course materials due to the ever-growing body of knowledge and the fact that students have to work and study, leaving them with little to no time to study taught content [1][2]. This calls for effective learning strategies other than repeated study, which has limited effectiveness [3].

Research shows that mnemonics are a powerful way to learn and recall large amounts of information when needed, especially in memory-intensive courses [4][5] or professions that require remembering information, e.g., in a certain order [6]. Creating meaningful mnemonics and using them effectively constitute one of the most valuable ways by which students can enhance memory – be it in engineering [7], science [8], social science [9], mathematics/statistics [10], or humanities [11][12]. Generating one's own mnemonics is an effective way to remember taught material because it links new information to what students already know, are familiar with [7], their personal experiences, and prompts them to deeply process the material [7][8][10]. Moreover, there is a considerable expenditure of mental effort on the front end of the encoding process, which enhances memory in the long run [9].

Remembering is very important in learning; otherwise, we relearn all we have learned. Hence, in Bloom's taxonomy, it is the foundational level upon which higher-order cognitive processes such as understanding build [13]. In particular, mnemonics not only help recall information, they free up cognitive resources for higher-order thinking and help reduce stress and anxiety during tests [10][14].

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Although mnemonics have a long history of helping people remember easily forgotten information [15] [8][13], today, they are underused in higher education [16][15], especially in memory-intensive courses where students must: (1) learn and remember a lot of material [17], and (2) master an entirely new lexicon before progressing to learn more complex concepts [9]. One plausible reason behind their low usage is that many instructors and students are unaware of their effectiveness and/or how to use them effectively to enhance long-term learning [18][14][16]. Research shows that people who know about different learning strategies, such as mnemonics, are more likely to use them [19].

However, despite overwhelming evidence on their effectiveness, McCabe [19] found that "although many students know what mnemonics are, they do not judge them to be as beneficial for learning compared to other common study strategies" (p. 10). Another reason why mnemonics are underused is that the pragmatic demands of the classroom may not be conducive or amenable to their use [17]. This calls for external pedagogical tools equipped with persuasive strategies that can support both instructors and students in the effective use of mnemonics to enhance long-term learning. However, there is a scarcity of such tools that support and instruct students and instructors on how to create effective mnemonics and/or help them create them easily and creatively [4][5]. In particular, there is a scarcity of guidelines for the design of interactive, mnemonics-creation, and retrieval-practice tools aimed at learning memory-intensive subjects and courses effectively. To bridge this gap, this paper proposes a novel framework called "RADAR" that can help and guide educators and developers in implementing effective MESGs at various educational levels to promote life-long learning.

## 2. Background and Related Work

This section provides theoretical background and an overview of existing frameworks for developing educational serious games (ESGs).

### 2.1. Mnemonics

Mnemonics are memory aids that serve as a cue or bridge to recall information from long-term memory when needed. Mnemonic techniques such as acronyms and acrostics are based on cognitive psychological principles, with Wellman [20] arguing that "it is a well-established principle in psychology that the ability to remember is dependent on a person's employment of mnemonic strategies" (p. 37). Mnemonics utilize meaningfulness, visuals, concreteness, and connections in fostering recall. They are effective because they (1) transform non-meaningful or difficult-to-remember information into concrete, visual, and meaningful proxies through an elaborative process; and (2) create an association between target information and a cue such as keyword, acronym, or image with which the student is already familiar, making the information to be more memorable. Hence, the four main properties of an effective mnemonic cue include meaningfulness, elaboration, association, and visualization [21], which are instrumental to the recall of difficult-to-remember target information.

### 2.2. Retrieval Practice

Retrieval practice is a study method that requires learners to engage with target material in an active rather than passive way. Research shows that retrieval practice is a powerful mnemonic enhancer, leading to large gains in long-term retention compared with repeated studying [22][3]. According to [23][24], retrieval is neither a neutral nor uninfluential event in the learning process. Rather, it produces and strengthens learning [25], with Karpicke and Blunt [23] arguing that retrieval practice may actually be a more powerful learning activity than information encoding. Although retrieval practice can be effective without feedback (i.e., showing the correct answer), provision of feedback enhances the benefits of self-testing. More importantly, retrieval practice promotes the acquisition of knowledge that can be flexibly retrieved from long-term memory and transferred to different contexts. It helps to consolidate long-term memory, with important implications for educational practice [22]. Research shows that retrieval of previously studied material is more likely to foster long-term retention than repeated study or even elaborative encoding [3][23]. Given its importance, this paper focuses on the retrieval of encoded information from long-term memory using serious games to consolidate learned information.

## 2.3. Serious Games

Serious games are interactive applications that use game elements for educational rather than entertainment purposes. Research shows that they hold prospects in promoting knowledge acquisition and skill development through training [26][27]. Hence, they are applied in several domains such as aviation, education, and health care. Serious games have begun to gain traction in education to promote active learning in a manner that provides enjoyment and fun [2][28]. However, there is a scarcity of "tools for effectively and deeply infusing pedagogy and instruction inside digital games" (p. 1) [28]. The current paper aims to bridge this gap by proposing an application-design framework that can facilitate mnemonics game development to promote long-term memory.

## 2.4. Existing Frameworks

This subsection focuses on relevant frameworks for designing and developing ESGs aimed to promote great user experience and behavior change among users turned players in various domains.

### 2.4.1. ASGD Framework

Djafarova et al. [29] proposed the Art of Serious Game Design (ASGD) framework and methodology for developing serious games. The framework comprises four key game components (storytelling, gameplay, user experience and learning) placed in four equal circle quadrants to emphasize their equal importance in the design process. Gameplay, for example, entails the way the player interacts with the game or other players in the case of multiplayer games. While this framework is useful for designing and developing serious games in general, it is not focused on MESG design, which is a niche area of research and game design that requires attention.

### 2.4.2. LM-GM Framework

Lim et al. [30] proposed the Learning Mechanics-Game Mechanics (LM-GM) framework to foster ESG analysis, design and reflection upon various pedagogical and game elements. The framework includes a set of pre-defined game elements (e.g., roleplay, competition, reward and feedback), which can be mapped to a set of pre-defined pedagogical elements (e.g., demonstration, exploration, simulation and analysis). While the framework is vital to game design, the authors, who used it to analyze the third-person-shooter game *Re-Mission*, showed it is especially useful for the analysis of existing games.

### 2.4.3. Moon and Khan's 10 Game Design Guidelines

Moon and Khan [31] proposed a set of 10 gamification design guidelines for professionals in clinical and research roles to bridge the gap between therapeutic approaches and creative design. The guidelines include: 1) Set clear goals and objectives; 2) Design around core mechanics; 3) Maintain game flow and player experience; 4) Strike a balance between ability and challenge; 5) Use storytelling and immersion; 6) Provide reward; 7) Support regular feedback and reflection; 8) Support auditory and visual elements; 9) Support social affordances; and 10) Evaluate the game with users and experts to elicit useful feedback. While the guidelines are applicable to other domains than health, they are not focused on MESG design.

## 2.5. Research Gap

The review shows there is a lack of mnemonics-based frameworks that can help educators, designers and developers realize effective serious games aimed at promoting long-term learning. While the reviewed frameworks can be instrumental to design, they, like many others [32][33][34], do not prescribe how different game components and/or persuasive strategies can be combined in an orderly step-by-step fashion to realize a complete serious game. Hence, this paper proposes a mnemonics-based step-by-step framework (coupled with user experience and persuasive design principles and guidelines) and shows how it can be utilized in developing an effective MESG aimed at fostering long-term learning.

## 3. Method

We began our framework development by reviewing the literature to uncover existing mnemonics-based frameworks and their use to inform the development of ESGs [5] and analyzing mnemonics-based apps on the app stores to uncover their design characteristics [2]. In both studies, we found that there is a lack of frameworks that can help guide the design and development of MESGs. Consequently, based on the results of the review and analysis of the apps on the Google and Apple app stores, we developed a framework which we called "RADAR" and a set of design principles (encapsulated in the memorable acronym "FAST-BAROGRAM") to inform the creation of future MESGs. In this section, we focus on the backdrop of the RADAR framework and its validation. In the discussion section, we elaborate on the FAST-BAROGRAM design principles proposed for the development of effective MESGs.

### 3.1. RADAR Framework: The Big Picture

The RADAR framework is a part of an educational toolkit being developed to support students' learning in memory-intensive courses. Called "SANKOFA" ("**S**ave **A**ll **N**ew **K**nowledge **O**ptimally and **F**etch **A**ccurately"), the toolkit helps both instructors and students to encode and save instructional materials using interactive mnemonics creation tools and retrieve them accurately (as well as actively) using retrieval practice games. Metaphorically, the acronym "SANKOFA" is akin to the Ghanaian Akan term "*Sankofa*," which literally means, "to go back and fetch lost knowledge so as to move forward" [35]. In line with the Sankofan philosophy of always going back to get what is left behind as one moves forward, the RADAR app, focused on life-long learning, is used to go back to retrieve encoded knowledge from long-term memory, receive feedback, review and reflect on it so as to reinforce it [36][37].

### 3.2. Validation of RADAR Framework

To validate the framework, we carried out a three-test, biology-content experiment among 52 participants from a Canadian university. A recruitment survey was used to screen candidates for the experiment, with the main inclusion criteria being that a participant must be a student/alumnus of the university and not be studying biology as a course. Eligible candidates were randomly assigned to two groups. The demographic profiles of the experimental and control groups were similar. For example, 45% and 55% of the RADAR group were males and females, respectively. Similarly, 41%, 55% and 4% of the control group were males, females, and others, respectively. Moreover, 83% and 82% of the RADAR and control groups, respectively, ranged from 18 to 24 years old, while the respective remaining percentages were above 24. Finally, 87% and 77% of the RADAR and control groups, respectively, were undergraduate students, while the respective complementary percentages were graduate students and alumni.

The experimental group ($n = 30$) used a mnemonics creation tool [38] and the RADAR game [39] to learn and practice the retrieval of the target information, while the control group ($n = 22$) used a printed PowerPoint deck, pen and paper, and a learning technique of their choice such as rote memorization.

In the experiment, both groups learned six biology topics for 45 minutes on day 1 (T1) after watching a 10-minute video lecture and took recall-based (term-listing) and recognition-based (multiple-choice) tests after a five-minute break. One week later, both groups retook the test without revision (T2) and after a 15-minute revision (T3). The six biology topics, ranging from simple to difficult, include Biology Organization Levels (BL), Biology Organization Disciplines (BD), Cranial Nerves (CN), Cranial Nerve Functions (CF), Krebs Cycle Substrates (KS), and Krebs Cycle Reactions (KR). See [39] for the experimental details and Table A1 for the mnemonics used to encode the six topics. The choice of biology was deliberate: it is a facts-based course with a large volume of (difficult) content to be learned.

# 4. Results

This section describes the RADAR framework, its associated design principles, its implementation and validation using a game prototype for a user interface course in computer science as proof-of-concept.

## 4.1. RADAR

The RADAR is a framework for developing an information retrieval and knowledge consolidation app that enables the learner to retrieve encoded information from long-term memory using mnemonic cues, receive feedback on performance, reflect on the feedback, and reinforce acquired knowledge. Figure 1 shows the RADAR framework and its operational mechanism. It comprises four sequential cognitive tasks (Recollection, Association, Decoding and Artifacts Review), which are described as follows.

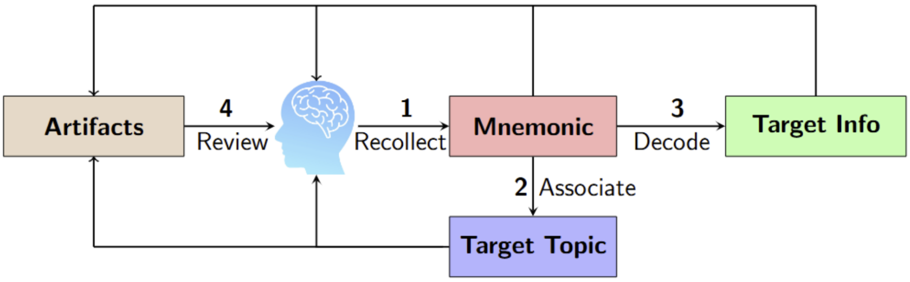


**Figure 1:** RADAR framework showing the four key cognitive stages of retrieval practice for enhancing memory. Brain icon source: https://www.dreamstime.com.

### 4.1.1. Recollection

Recollection entails the recognition or recall of created mnemonics in the learner's toolbox from long-term memory. For example, if a student has used an interactive tool to create and save the mnemonic "OCEAN," representing the "Big-Five Personality Traits," in a database, the Recollection step of the RADAR is used to recognize the correct mnemonic in the midst of incorrect ones or recall the mnemonic from memory, which the app compares against that in the database to see whether it is correct or not.

### 4.1.2. Association

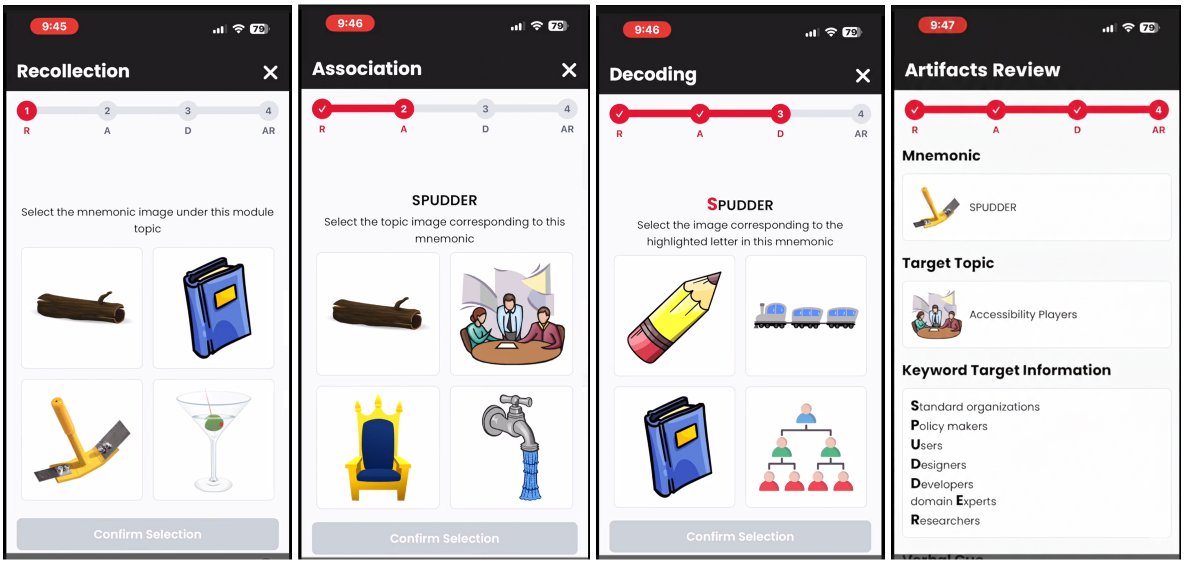
Association entails the linking of the recollected mnemonic to its corresponding target topic. For example, this step can help the learner connect the mnemonic "OCEAN" to the target topic "Big-Five Personality Traits" such that whenever the word "OCEAN" is said, the Big-Five readily comes to mind.

### 4.1.3. Decoding

Decoding focuses on the deciphering of each of the mnemonic terms by linking it to the corresponding word or phrase in the target information. For example, "O," "C," "E," "A," and "N" are linked to "Openness," "Conscientiousness," "Extraversion," "Agreeableness," and "Neuroticism," respectively, all of which are the target information for the Big-Five Personality Traits.

### 4.1.4. Artifacts Review

Artifacts Review involves going over and reflecting upon the essential information associated with each recollected mnemonic including the target topic, target information, mnemonic-topic conceptual connection, and expressive images associated with the mnemonic. This final cognitive process helps the learner reinforce the learned information associated with the mnemonic and target topic of interest.



Select the mnemonic image under this module topic

SPUDDER

Select the topic image corresponding to this mnemonic

**S**PUDDER

Select the image corresponding to the highlighted letter in this mnemonic

**Mnemonic**

SPUDDER

**Target Topic**

Accessibility Players

**Keyword Target Information**

**S**tandard organizations
**P**olicy makers
**U**sers
**D**esigners
**D**evelopers
domain **E**xperts
**R**esearchers

**Figure 2:** Standard app prototype showing the implementation of the RADAR framework. In each stage, the player is expected to recognize the correct visual representation of the target information, e.g., mnemonic image (first stage), target topic image (second stage), and target item image (third stage), by clicking on the "Confirm Selection" button, after which they are provided feedback as to the correctness of their choice. License under CC BY-NC-SA. Icon sources: https://www.bigrocksupply.com, https://www.flaticon.com, https://pixabay.com, https://commons.wikimedia.org, https://clipart-library.com, https://wiki.dtonline.org, https://dukeheights.ca.

### 4.2. Demonstration

Figure 2 shows the RADAR implementation in a basic MESG prototype for a user interface course comprising several topics that are memory intensive. In the first screen, the player engages in mnemonic recollection (recognizing the image that represents the mnemonic of interest: "SPUDDER"). In the second screen, the player engages in mnemonic-topic association (i.e., associating the mnemonic "SPUDDER" with its target topic "Accessibility Players"). In the third screen, the player engages in mnemonic decoding one term at a time, e.g., decoding "S" into the image equivalent of "Standards Organizations." Finally, in the fourth screen, the player engages in artifacts review, which entails viewing all essential information related to the mnemonic, reflecting on it, and reinforcing their knowledge.

### 4.3. Integration of Design Principles

The RADAR game is underscored by key user experience and persuasive design principles, which were synthesized from the extant literature and are encapsulated in the acronym "FAST-BAROGRAM" to aid memory. In the context of MESG design, FAST-BAROGRAM represents **F**eedback, **A**esthetics, **S**torytelling, **T**unneling, **B**alance, **A**utonomy, **R**eflection, **O**bjectives, **G**roup affordances, **R**eward, **A**udio-visuals, and **M**echanics. The user experience design principles (e.g., Aesthetics) are aimed at promoting application adoption and user engagement, while the persuasive design principles (e.g., Feedback that reinforces knowledge of target information) are focused on fostering desired learning outcomes [40]. The 12 design principles, some of which are inherently supported by the framework (e.g., Tunneling, Reflection) or already built into the prototype (e.g., Aesthetics, Feedback, Reward) shown in Figure 2, are explained in detail in the discussion section with typical implementation examples when necessary.

### 4.4. RADAR vs Reviewed Frameworks

Holistically, the RADAR framework comprises a four-step retrieval practice process and a set of design guidelines that derive from the design principles presented in the prior subsection, which work together to realize an effective MESG. To uncover its unique offerings, the RADAR is compared with the prior frameworks based on key criteria as shown in Table 1. For example, while the RADAR is focused on

MESGs, the other frameworks are generic, meaning they are not tailored for MESG design. Similarly, while the RADAR outlines the steps in a sequential fashion on how to implement the game flow, others do not. In the context of this paper, we refer to game flow as the series of steps that the *player* will take to accomplish the learning outcome of interest. Game flow is differentiated from game design method, which refers to the sequential steps taken by *designers/developers* to realize a game. Moreover, end-to-end transparency entails the extent to which a full-fledged game that accomplishes a learning outcome can be easily created from start to finish based on the steps laid out in the framework and its accompanying design principles and guidelines. Design principles refer to high-level design concepts such as Aesthetics and Feedback, while design guidelines refer to specific recommendations provided to designers/developers to achieve the design principles in concrete terms. An example guideline relating to the Group Affordances principle is "implement a leader board to enable players to compare their performances." Finally, learning outcomes refer to clear, observable and measurable goals/objectives of a game, which relate to knowledge and skill acquisition. Examples of learning outcomes fostered by the RADAR framework include knowledge recognition and recall. Finally, the Bloom-taxonomy-based criterion refers to the cognitive processes in Bloom's Learning Pyramid that the different frameworks support. For example, the RADAR framework supports mainly remembering (implemented as the recognition or recall of the right answer to a prompt), which has the potential to free up cognitive resources for higher-order cognitive processes including understanding, analysis and synthesis [39].

**Table 1**
Comparison of the RADAR with existing serious game design frameworks based on a set of fourteen key criteria elicited from the individual frameworks. RADAR: Recollection-Association-Decoding-Artifacts-Review framework, ASGD: Art of Serious Game Design framework, LM-GM: Learning Mechanics-Game Mechanics framework. ✓: supported, ✓*: partially supported, ×: not supported.

| Criterion | RADAR | ASGD [29] | LM-GM [30] | Moon and Khan [31] |
|---|---|---|---|---|
| Literature-informed | ✓ | ✓ | ✓ | ✓ |
| Cross-domain | ✓ | ✓ | ✓ | ✓* |
| Mnemonics-focused | ✓ | × | × | × |
| End-to-end transparency | ✓ | × | × | × |
| Sequential game flow | ✓ | × | × | × |
| Sequential game design method | × | ✓ | × | × |
| Game development | ✓ | ✓ | ✓* | ✓ |
| Game analysis and evaluation | ✓ | ✓ | ✓ | ✓ |
| User experience design principles and guidelines | ✓ | ✓* | × | ✓ |
| Persuasive design principles and guidelines | ✓ | ✓* | ✓* | ✓ |
| Proof-of-concept app demonstration | ✓ | × | × | × |
| Experimental validation | ✓ | × | × | × |
| Bloom-taxonomy-based | ✓* | ✓* | ✓ | × |
| Learning-outcomes-linked | ✓ | ✓ | ✓ | × |

## 4.5. Evaluation Outcome

The results of the analyzed data collected from the biology-based experiment showed that there was no significant difference between the RADAR group ($M = 0.63, SD = 0.20$) and control group ($M = 0.64, SD = 0.21$) regarding the recognition test overall. However, regarding recall, there is a significant difference between the RADAR group ($M = 0.55, SD = 0.27$) and control group ($M = 0.47, SD = 0.27$) at the overall level at $p < 0.001$ as evident in Figure 3 and Figure 4. (See [39] for the detailed analyses of variance and the results for the recall and recognition tests.) Specifically, regarding recall (Figure 3), our analyses of variance showed that, for three of the most difficult topics (CN, KS and KR), the cognitive performance of the RADAR group was significantly higher than that of the control group at $p < 0.05$, but this was not the case regarding the other topics (BL, BD and CF) [41].

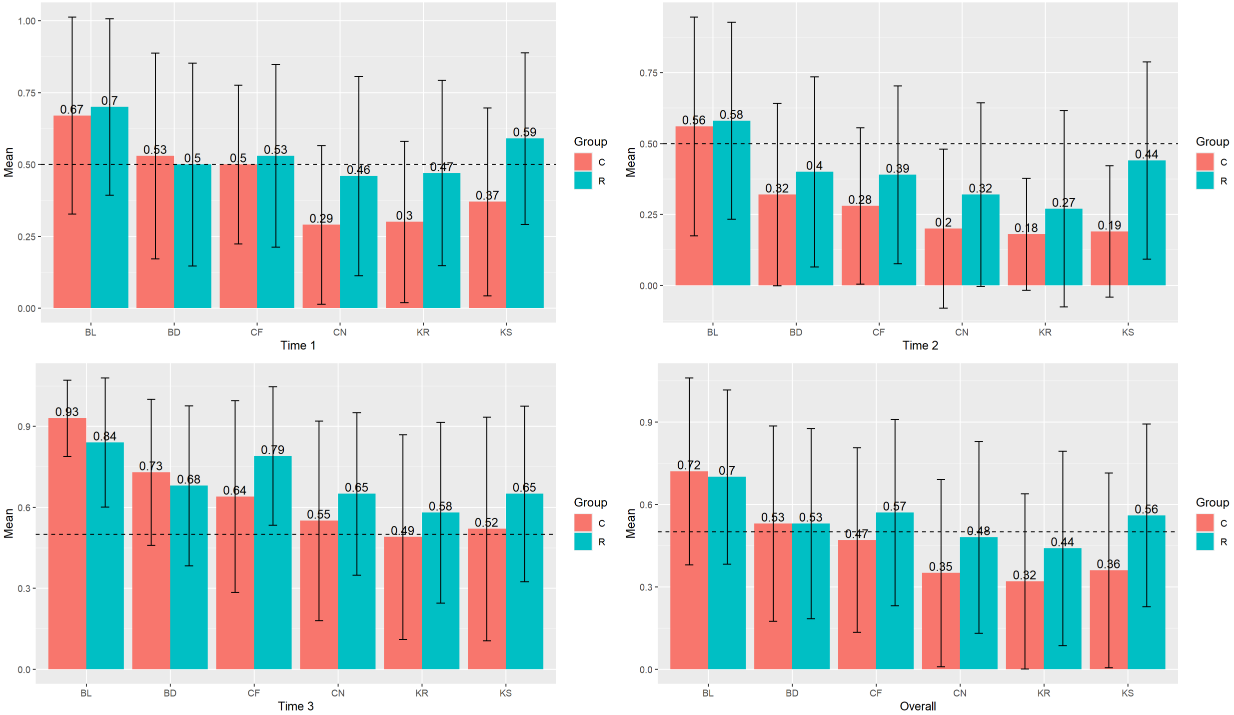


**Figure 3:** Topic-based recall scores for the three timepoints. Error bar: standard deviation. C: Control, R: RADAR. The scores range from 0 to 1 [41].

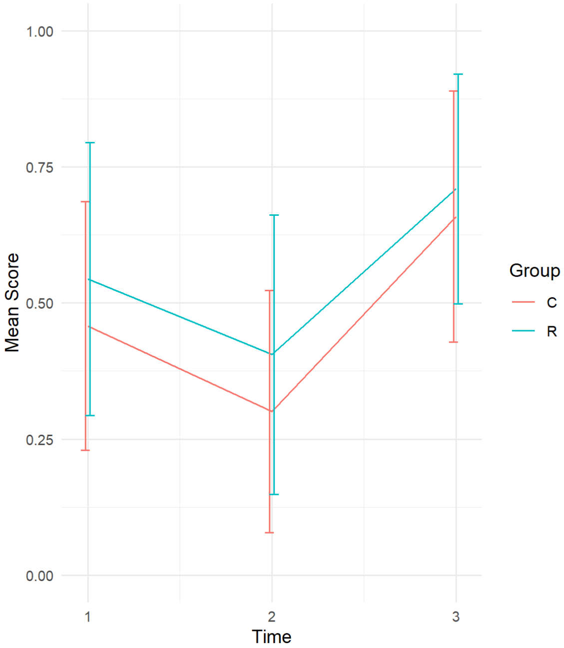


**Figure 4:** Overall recall scores at the three timepoints. Error bar: standard deviation. C: Control, R: RADAR. The scores range from 0 to 1 [41].

## 5. Discussion

We discuss the results of the validation of the RADAR and the design guidelines for effective MESG design. Finally, we discuss the conceptual connection between the FAST-BAROGRAM design principles and the Self-Determination Theory (SDT), which underscores the development of effective serious games [42], and the value proposition of the RADAR versus existing non-mnemonics-based frameworks.

### 5.1. Effectiveness of RADAR Framework and Game

Our analysis of the two types of cognitive performance shows that, regardless of time, both the RADAR and control groups performed significantly better in the recognition than recall test ($p < 0.001$). This, in the context of Bloom's taxonomy, indicates that multiple-choice questions that test the ability to recognize the right answers (and by extension understanding) are easier to pass than short-answer questions that test the recall or remembering of facts. As shown in Figure 4, both the RADAR and control groups performed significantly worse at T2 than at T1 due to the memory decay effect, but significantly better at T3 than at T2 and T1 due to the revision effect. These findings indicate the need for learners to refresh their memory from time to time to prevent their memory of learned information from "decaying to naught" due to lack of repeated and/or frequent revisions [41].

Overall, there is no significant difference between both groups in the recognition task. However, the RADAR group performed significantly better than the control group in the recall test overall, with the former achieving a 20% increase in participants' scores on average. In particular, the group difference between the RADAR and control conditions is significant with respect to three of the four difficult topics. Regarding CN, KR and KS, the RADAR group increased by 37%, 38% and 56%, respectively, compared with the control group. However, regarding the other topics, particularly the simple topics such as BL and BD, the difference between both groups is not significant as evident in Figure 3, where the overall group difference is minimal as in BL or non-existent as in BD.

In a nutshell, the results of our analysis indicate that mnemonics-based games, such as the implementation of the RADAR framework, are more effective in enhancing recall than rote memorization, especially in unfamiliar topics such as CN, KS and KR that students may find very difficult to learn without the aid of memory-enhancing strategies such as acrostic mnemonics (Table A1). Based on these findings, we call on educators across all levels of education to begin utilizing mnemonics-based serious games, grounded in cognitive theories and validated frameworks, to enhance long-term learning in memory-intensive courses such as biology and psychology that may be difficult to learn otherwise.

### 5.2. RADAR Design Guidelines

We discuss the incorporation of user experience and persuasive design principles in RADAR-based games using Moon and Khan's [31] 10 design principles revised to 12 and christened "FAST-BAROGRAM". Just as the literal barogram represents a barographic trace that visualizes or measures atmospheric pressure, FAST-BAROGRAM can be viewed as the digital barometers (or metrics) for gauging the effectiveness of a RADAR-based game. Its 12 design principles, most of which are found in other serious game design frameworks such as IN-3PACIFIC (e.g., Agency, Narrative, Feedback) [2] and the SDT (i.e., Autonomy, Competence, and Relatedness) [42], can be incorporated into the implementation of the RADAR framework to increase effectiveness, usability, utility, adoption, and motivate behavior change.

**Feedback:** In each of the first three steps of a RADAR-based game, the player should be provided with immediate and/or multimodal feedback in the form of text, visual or audio, e.g., when decoding mnemonic terms. Informative immediate feedback reinforces knowledge. It helps the player to know whether their response is right or wrong and provides them with a sense of competence when they are right and an opportunity to try again or see the correct answer when they are wrong [11].

**Aesthetics:** RADAR-based games should support aesthetic design (aka hedonic quality) to evoke positive emotions and deliver an enjoyable use experience [40]. These can be achieved by the choice of colors, visual elements used and their layout on the screen [43]. Aesthetics positively impacts the perceived persuasiveness of interactive systems aimed at behavior change [44], which in turn can increase perceived usability, credibility and adoption [45][46].

**Storytelling:** RADAR-based games can support storytelling and immersion to make them relatable, memorable and the player entrenched in the narrative, detached from reality, time and place. To increase effectiveness, the story should be set at a particular place and time, as the C-SHARP framework recommends, with the player assuming the role of a key character such as a superhero with external or internal conflicts [2]. For example, during the decoding stage, a RADAR-based game may require the player to shop for the components of web accessibility in a virtual-reality store that is unsafe within a certain period. In this task, akin to a rescue mission, the player, equipped with a mission brief (containing the mnemonic “ADA CUBE”) must combat “bad guys” and avoid fatal weapons to fill their shopping cart with the right components from a set of labeled jars sitting on the shelf, with the right labels representing the target terms (**A**uthoring tool, **D**esigner/Developer, **A**ssistive technology, **C**ontent, **U**ser, **B**rowser, **E**valuation tool) mapping to the mnemonic terms of interest [39].

**Tunneling:** This entails breaking a given goal or game objective into steps so that it can be achieved easily. Research in the field of persuasive technology shows that when tasks are broken down into small steps, users are more likely to accomplish them [47]. An example of Tunneling is the software installation wizard. Similar to the installation wizard, the RADAR framework, if followed to the letter, fosters tunneling, a streamlined process, starting with Recollection and ending with Artifacts Review.

**Balance:** In RADAR-based games, there should be a balance or alignment between the player’s ability and the game challenge to foster flow (aka optimal experience) [48]. This can be achieved by providing difficulty levels, which allow novice players to start with an easy challenge and proceed to more difficult ones as they progress. For example, players can begin with verbal recognition (multiple-choice answers) and end with verbal recall (entering the right answers from memory).

**Autonomy:** Just as in many interactive systems that provide the user a locus of control to make the user experience worthwhile, the player should be granted autonomy in RADAR-based games. For example, they can be allowed to choose their avatar, choose a certain difficulty level that matches where they are at in their learning journey, determine the look and feel of the game, and move to any of the four stages of the game after unlocking them, pause the game, if need be, and continue later.

**Reflection:** The RADAR framework implicitly supports reflection, as the “Artifacts Review” stage enables the player to reflect on the information associated with each retrieved mnemonic. As shown in Figure 2, in the review stage, the player is allowed to go over all of the information associated with the mnemonic of interest including the target topic (e.g., Accessibility Players), target information (e.g., Standards Organizations, Policy Makers), and other tidbits. This final review, which fosters reflection, can help strengthen the long-term memory of the target information linked to its mnemonic. However, reflection can be integrated into other stages of the RADAR game. For instance, it can be incorporated in the Decoding stage, e.g., in app feedback following a player’s response to a decoding prompt [36].

**Objectives:** RADAR-based games should support clear and concise objectives that can be tracked over time. While the RADAR framework supports the primary objective of promoting long-term memory of target information through retrieval practice, individual games can support secondary objectives such as verbal recognition, visual recognition, verbal recall, etc. The game prototype shown in Figure 2 supports visual recognition of the right answers, with player’s performance tracked.

**Group affordances:** To foster relatedness, as espoused in the SDT, RADAR-based games can support social features such as cooperation and competition [49]. Regarding the latter, leader boards, which enable players to compare themselves based on their performance, can be used to motivate players by way of competition, with highly motivated players desiring to be at the top of their leader boards.

**Reward:** RADAR-based games should support reward elements such as points and badges. For example, in each stage of the framework, the players should be allowed to earn virtual points, which have the potential to motivate them to keep playing the game and compare themselves with others.

**Audio-visuals:** RADAR-based games can support audio-visual content and feedback (sound, images, video and haptic) to enhance the use experience [50]. For example, each mnemonic can be linked to an expressive image to enhance recall as seen in “SPUDDER” mapped to a visual implement (Figure 2).

**Mechanics:** Above all, specific types of RADAR-based games can support physical mechanics such as controlling objects as in the game of Tetris [e.g., directing, in the Association stage, a labeled falling object (representing a mnemonic) into the right bucket (representing the target topic)] or shooting a target (e.g., the correct target word linked to a mnemonic term) and dodging fatal weapons in the process. Compared with passive learning, this type of physical mechanics has the potential to foster user engagement and positive experiential learning outcomes that can promote knowledge retention.

### 5.3. Nexus between FAST-BAROGRAM and SDT

Most of the design guidelines (e.g., Autonomy, Balance, and Group Affordances) in FAST-BAROGRAM relate to the SDT, which is often used in making serious games more effective. The SDT postulates three basic psychological needs (Autonomy, Competence, and Relatedness) that, if satisfied, foster intrinsic motivation and optimal experience. It serves as an effective framework for designing engaging user experiences that foster intrinsic motivation (e.g., enjoyment) rather than are driven by extrinsic motivation. Typically, the SDT entails providing players with choices and agency (Autonomy ⟹Autonomy), offering skill-building challenges aligned with players' abilities (Competence ⟹Balance), and fostering social connectedness among players (Relatedness ⟹Group Affordances). The other design guidelines can be used in promoting the three core psychological needs of SDT. For example, Feedback, coupled with Audio-Visuals, can be used to inform players about their competence, e.g., allowing them to know whether their response to a prompt is correct or incorrect. Reward, in the form of virtual points and badges, can be used to remunerate players for their competence and positioning them on a leader board based on their relative performance. More importantly, Storytelling, in the form of narratives that involve the user playing one of the main characters, relatable plots, places, events, and milieus, can be used to foster not just social, but socio-ecological, connectedness. The *Acronimps* mnemonics game situated in medieval settings, developed by Fung [39], is a typical example of how narratives can be integrated into RADAR-based games to foster socio-ecological connectedness that transcends learning.

### 5.4. RADAR's Value Propositions

The comparative analysis shows that all of the frameworks share some valuable commonalities (Table 1). For example, essential criteria, such as being informed by a literature review, applicable across several disciplines (e.g., biology, psychology, history), used for game development and evaluation of existing games, cut across all four frameworks. However, the RADAR offers a set of unique value propositions that the other frameworks do not provide in the context of long-term learning. While the RADAR meets over 90% of the evaluation criteria, the other frameworks only meet less than 65%. For example, the comparative analysis shows that most of the existing design frameworks are generic, unlike the RADAR which is focused on mnemonics-related games aimed at promoting desired learning outcomes such as knowledge retention in memory-intensive courses. Specifically, only the RADAR framework presented a proof-of-concept demonstration of how it can be used to implement a minimally viable functional app focused on accomplishing the behavior change of interest: promotion of long-term learning through mnemonics-based retrieval practice (Figure 2). In addition, only the RADAR framework was validated using a true experimental design that involved a control group. In a nutshell, it is noteworthy that the simple, clear and transparent composition of the RADAR framework – a four-step game workflow with well-defined and well-delineated cognitive tasks (Figure 1) – makes it easy for developers to implement. In contrast, the other frameworks are more complex and less straight to the point with regard to their implementation to realize a functional app. An example framework, which one may describe as complicated with limited explanation, is the ASGD framework with four interacting major components – storytelling, gameplay, user experience and learning – each of which is composed of sub-components interacting as well [29]. Unlike the RADAR with four clear-cut steps to achieve the desired goal, the ASGD lacks transparency and, thus, is not easy to understand how the various components in the framework fit together to realize an end-to-end game that achieves a well-defined learning goal.

## 6. Conclusion

In this paper, we presented and validated a mnemonics-based framework called "RADAR" for implementing MESGs aimed at promoting long-term memory. As proof-of -concept, we demonstrated its implementation in a biology-content game featuring six topics ranging from simple to difficult. The results of our experiment showed that the RADAR game is more effective than rote memorization, particularly in learning difficult topics such as CN, KR and KS. The findings suggest that the RADAR framework can be utilized by educators and developers in creating effective MESGs in various courses such as biology, psychology and history to foster long-term learning. Moreover, we provided a set of mnemonics-based design guidelines, encapsulated in the acronym "FAST-BAROGRAM," to increase the effectiveness of MESGs. To the best of our knowledge, the RADAR is the first mnemonics-based framework that has been proposed and validated in the literature to support instructors and developers in creating effective MESGs to promote long-term learning in memory-intensive courses. In future work, we plan to continue validating the RADAR framework in other courses, contexts and countries.

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## Declaration on Generative AI

The author has not employed any Generative AI tools.

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## A. Biology Intro Material: Recalled Information

**Table A1**

Mnemonics decoded using the RADAR app and their corresponding target topics and information. BL: Biology Organization Levels, BD: Biology Organization Disciplines, CN: Cranial Nerves, CF: Cranial Nerve Functions, KS: Krebs Cycle Substrates, and KR: Krebs Cycle Reactions [38][39].

| Topic | Target Information | Mnemonic |
|---|---|---|
| BL | Atom, Molecule, Organelle, Cell, Tissue, Organ, Organ System, Organism, Population, Community, Ecosystem, Biosphere | At Moldova's Original Cell, Tutsi Organized Organic Orgy Popular, Commanding Economic Boom |
| BD | Chemistry, Molecular Biology, Cellular Biology, Cellular Biology, Histology, Anatomy, Physiology, Biology, Population Biology, Community Ecology, Ecology, Biogeography | Chemist Mollahs Callout Cellular Historians Analyzing Physical Bones Populating Compton, Echoing Bigotry |
| CN | Olfactory, Optic, Oculomotor, Trochlear, Trigeminal, Abducens, Facial, Vestibulocochlear, Glossopharyngeal, Vagus, Accessory, Hypoglossal | Oldfactory Optician's Oculi Trouble Trigonometrically, Abductor's Facial Vestibule Glossing pharyngeally Vagina Accessory Hypoglossal |
| CF | Sensory, Sensory, Motor, Motor, Both, Motor, Both, sensory, Both, Both, Motor, Motor | Seers Say Move Motor, But Motorist Bosses Say Big Brain Matters Most |
| KS | Acetate, Citrate, Isocitrate, Ketoglutarate, Succinyl CoA, Succinate, Fumate, Malate, Oxaloacetate | Acetic City Isobel's Kettle gluttonously Sucks Fumy Malt Oxaloacetic |
| KR | Condensation, Isomerization, Oxidative Decarboxylation, Oxidative Decarboxylation, Phosphorylation, Oxidative Decarboxylation, Hydration, Oxidation | Condemned Isometrician Oxton Overloaded Pharaoh's Ox (with) Hydraulic Oxide |