Designing an Interactive Tool for Mnemonics Creation and Knowledge Retention

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Abstract

Research shows that mnemonics are an effective learning technique, yet few tools support mnemonics-based long-term learning. We designed and evaluated a mnemonics-creation tool, the SAVE Tool, to promote active learning and retrieval practice. Forty-five participants were assigned to experimental and control groups and viewed a 10-minute biology lecture covering six topics. They completed recall and recognition tasks after a 45-minute practice session (T1), one week later without revision (T2), and after a 15-minute revision (T3). Results showed that the SAVE Tool group consistently outperformed the control group in recall across all time points, with statistically significant differences at T3 and for more difficult topics such as Krebs Cycle Substrates and Cranial Nerves. No significant group differences were found for recognition. These findings suggest mnemonics-based tools can enhance long-term learning without hindering understanding and should be integrated into memory-intensive courses.

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1 Introduction

1.1 Motivation

Higher education curricula in memory-intensive academic courses such as biology, psychology, and human-computer interaction (HCI) are characterized by a high volume of complex, structured information. This information is mostly encoded in formats requiring rote memorization, such as extensive lists, taxonomies, and corresponding concept pairs. For undergraduate students, it is academically challenging to master and retain this vast corpus of information. While students may succeed in remembering academic content in the short-term for assessment purposes, the long-term retention of this knowledge may be compromised.

To address these challenges, cognitive psychology suggests using mnemonic techniques. Mnemonics are memory aids that facilitate the encoding and long-term retention of information. Mnemonics work by organizing information into easily memorable chunks that connect new knowledge to existing concepts, a useful strategy that can be applied to education [16].

Using this theoretical foundation, this thesis proposes the design, development, and evaluation of an interactive web application. This tool assists students in the systematic creation and organization of mnemonic devices for their coursework. Providing a digital repository helps transform mnemonics into a structured study practice while also offering an open-access environment where students can contribute their own creations. The key functionalities will enable users to make mnemonics for specific topics in each course, improving the overall learning experience.

Research has begun to explore the development of interactive tools that utilize mnemonics. A recent review identified 9 studies focused on developing new or utilizing existing mnemonics-creation tools [1]. However, their analysis shows that there is a scarcity of empirical research delving into the impact of interactive mnemonics-based tools on academic performance metrics, specifically at the undergraduate level. Despite the research on the effectiveness of mnemonic techniques, the value of a dedicated software tool that uses those techniques in pedagogical settings is less explored.

1.2 Hypotheses

Based on the principles of active learning and structured processes present in the SAVE framework, the following hypotheses were proposed.

H1: The SAVE Tool will lead to higher students' performance across all six topics than the control condition

Participants who use the SAVE Tool will demonstrate higher overall learning performance, as measured by recall (RCL) and recognition (RCG) scores, than the Control group across all six topics. This aligns with evidence that active learning strategies, which engage learners in generating, organizing, and applying information, enhance understanding and long-term retention compared to passive study methods [17] [18].

H2a: The SAVE group will have higher recall scores than the Control group

Participants in the SAVE group will achieve higher recall scores than participants in the Control group. Recall tasks rely on effortful and generative retrieval, which is known to enhance long-term learning. One

study emphasizes that more challenging retrieval processes lead to better retention [19], and another demonstrates that testing produces stronger learning outcomes than restudying alone [20].

H2b: The SAVE group will have higher recognition scores than the Control group

Participants in the SAVE group will also achieve higher recognition scores than the participants in the Control group. Compared to recall, recognition involves lower retrieval effort. However, retrieval practice still improves recognition accuracy and can help transfer knowledge to varying contexts [21].

H3(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 1 compared to the Control group

This hypothesis proposes that students using the SAVE Tool will demonstrate advantageous immediate learning outcomes by achieving higher scores on both recall and recognition tasks at Time 1 compared to the Control group. This expectation is grounded in cognitive psychology research showing that structured encoding strategies lead to stronger initial memory traces and improved immediate retrieval [22] [23]. Frameworks that guide learners to organize and elaborate on new information have been consistently linked to better performance on early recall and recognition tests [24]. Accordingly, if the SAVE framework effectively supports deeper encoding, participants should exhibit an early performance advantage over those in the Control condition.

H4(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 2 compared to the Control group

The SAVE group will outperform the Control group on both recall and recognition tasks at Time 2, one week after the initial learning session. This hypothesis reflects the expectation that the SAVE framework promotes stronger long-term retention by supporting deeper, more elaborative encoding processes, mechanisms shown to improve delayed memory performance [22] [24]. Research on memory consolidation further suggests that information encoded with greater structure and meaningful associations is more resilient to forgetting across time delays [23]. Accordingly, if the SAVE Tool effectively strengthens the initial memory trace, participants in the SAVE group should retain more information after one week than those in the Control group.

H5(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 3 compared to the Control group

For both the recall and recognition tasks, the SAVE group participants' scores at Time 3 will increase compared to the Control group. This hypothesis highlights revising material using active learning, as implemented in the SAVE Tool, strengthens memory traces and enhances the recall and recognition of information over time. This effect is supported by research on the testing effect, which shows that effortful retrieval improves long-term retention [25], and on desirable difficulties [26], highlighting that challenging learning conditions lead to improved memory performance.

H6(a – c): The SAVE group will have higher overall scores and higher recall and recognition scores in difficult topics compared to the Control group

The scores of the participants in the SAVE group will achieve higher overall scores in difficult topics against the Control group. The difficult topics are further elaborated in Section 6.1.2 based on the participants' prior knowledge of the subjects. This hypothesis is based on evidence that structured encoding

strategies and elaborative learning techniques are especially beneficial when learners face complex or conceptually demanding material [22] [27]. Harder topics often require higher-order cognitive processes [3] [4], which can increase cognitive demands and make effective organization and integration of information critical for successful memory formation and retrieval. Because the SAVE framework is designed to guide learners in creating meaningful associations and reducing extraneous processing, it is expected to provide a disproportionate advantage under higher task difficulty. As a result, students using the SAVE Tool should exhibit superior performance relative to the Control group when learning challenging content.

H7: The recognition task for both conditions will have a higher score than the recall task overall

This hypothesis predicts that participants will achieve higher scores on the recognition task than on the recall task across both experimental conditions. This expectation is grounded in extensive memory research showing that recognition is generally cognitively easier than recall [28]. Recognition tasks provide external cues that guide retrieval, reducing the need for self-initiated search processes. As a result, recognition typically yields higher accuracy because it relies more on familiarity-based processing and less on effortful strategic retrieval [29] [30] [31] [32]. Therefore, it is expected that, regardless of group assignment, participants' recognition scores will surpass their recall scores.

H8: The SAVE Tool will be perceived as easy to use, useful, enjoyable and trustworthy, and users will be willing to adopt it

This hypothesis predicts that participants will perceive the SAVE Tool as easy to use, useful, enjoyable, and trustworthy, and that they will express willingness to adopt it. Prior research indicates that early positive impressions of a system, particularly regarding usability, perceived utility, and trust, are key predictors of engagement and sustained interaction in learning technologies [33] [34]. The Technology Acceptance Model (TAM) further suggests that these perceptions often strengthen with repeated exposure and hands-on experience, increasing users' confidence and intention to adopt a system over time [35] [36]. If the SAVE Tool effectively supports these core UX dimensions, participants are expected to report high ratings across ease of use, usefulness, enjoyment, trust, and willingness to adopt.

H9: Users will be willing to adopt the SAVE Tool given its perceived ease of use, perceived usefulness, perceived enjoyment, and perceived trustworthiness

This hypothesis predicts that users' willingness to adopt the SAVE Tool will be driven by its perceived ease of use, usefulness, enjoyment, and trustworthiness. According to the Technology Acceptance Model (TAM), early positive perceptions of usability and utility alone do not immediately translate into adoption intentions; rather, behavioral intention typically strengthens as users gain experience and confidence with a system [33] [35]. Similarly, research in educational technology highlights that enjoyment and trust play important roles in motivating learners to adopt new tools [37]. Therefore, if the SAVE Tool effectively supports these core UX dimensions, learners are expected to develop a genuine willingness to integrate it into their learning practices after meaningful engagement.

1.3 Contribution

We propose a toolkit to help students utilize mnemonics in pedagogical settings, referred to as the SANKOFA Toolkit. Introduced by Oyibo [38], the SANKOFA Toolkit provides students and instructors with a struc-

tured approach to generate and use mnemonics to encode instructional content and reinforce learning. The SANKOFA approach consists of two primary components: knowledge acquisition and knowledge retrieval, for which Oyibo proposed the SAVE and RADAR frameworks, respectively [39]. This thesis focuses specifically on the SAVE Tool, which is discussed in detail in Section 3.2. Oyibo [39] outlines the SAVE framework as four stages that learners have to follow to effectively retain newly acquired knowledge: (1) *Select* target information to encode, (2) *Associate* the target information with a mnemonic, (3) *Visualize* the mnemonic using expressive imagery, and (4) *Elaborate* on the mnemonic and target information through a meaningful conceptual connection.

The aim of this thesis is to apply the SANKOFA approach, specifically the SAVE framework, to (1) develop an educational tool that supports students in encoding and storing newly acquired knowledge for effective future retrieval, (2) evaluate the framework's effectiveness in promoting long-term learning, and (3) validate the SAVE framework itself, marking this thesis as the first empirical work to rigorously test and confirm its effectiveness.

2 Literature Review

This section delves into related literature about mnemonic-based interactive tools in the pedagogical domain.

2.1 The Challenge of Learning in Memory-Intensive Courses

Many important disciplines, such as biology or medicine, consist of foundational knowledge, including numerous definitions, complex models, and detailed lists. Students are expected to learn these core facts to be able to successfully apply them in practical, real-world scenarios using critical thinking skills. However, the extensive knowledge required to be memorized may overwhelm a student's learning capacity. The theory of memory from Atkinson and Shiffrin as shown in Figure 1 suggests that information in the short-term memory requires active rehearsal or practice to be stored in the long-term memory [2]. In addition to simple repetition, long-term retention benefits from a concept introduced by Craik and Lockhart known as elaborative rehearsal, a deeper form of processing in which new information is meaningfully connected to prior knowledge [22].

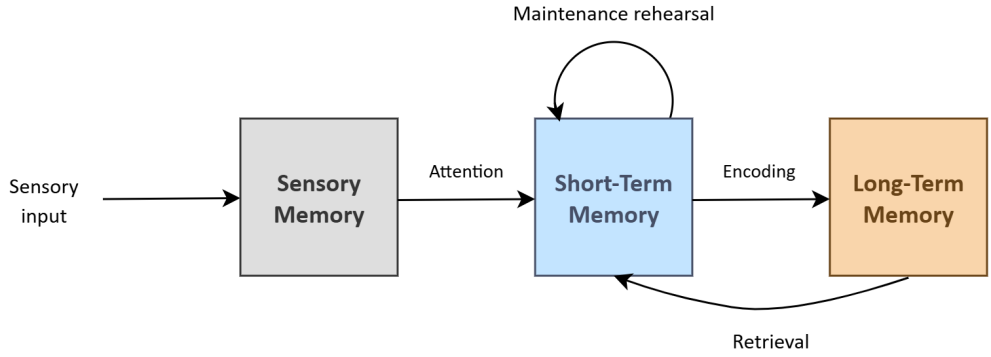


Figure 1: Atkinson and Shiffrin's Memory Model [2]

There is, however, a natural limit to how much information we can meaningfully process at once. Cognitive Load Theory [40] explains that our working memory has finite capacity, and complex or extensive material can easily exceed it. When this happens, the resulting cognitive load becomes too heavy for the mind to manage efficiently, disrupting the rehearsal processes required for long-term retention. As a consequence, students may struggle to learn material accurately and productively, limiting their ability to apply that knowledge to real-world problems.

2.2 Bloom's Taxonomy in University-Level Education

A crucial framework in formal education is Bloom's Taxonomy, a hierarchical model that helps classify educational goals into cognitive skills, introduced by Bloom et al. [3] and revised by Krathwohl [4]. The revised taxonomy (Figure 2) puts *Remember* at the first, foundational level. However, when faced with a vast corpus of knowledge in memory-intensive courses at the undergraduate level, a student may struggle to *remember* important concepts and hence, may not be able to apply the remaining processes, such as

Understand and *Create*, to do tasks that require the basic knowledge to be learned first, such as designing a user interface or diagnosing a medical condition.

This issue is often reflected in assessments. In a term- or semester-based education system, examinations are used to evaluate a large undergraduate student body. Research found that these examinations tend to focus on questions that test factual recall, using terms such as "define", "list", or "identify", in lieu of inquiries that elicit deeper synthesis or evaluation [41]. Therefore, students choose studying strategies that adapt to this structure, prioritizing short-term memorization through rote learning, which is found to be ineffective in long-term learning, over the development of conceptual understanding [42]. This leads to the existence of "inert knowledge", knowledge acquired and possibly recalled for an exam, but unutilized in solving real-world problems, undermining the goals of undergraduate education [43].

Hence, the concern moves away from the hierarchy of the taxonomy to the problem of building a strong knowledge base that is easily accessible for application and analysis. Educational interventions that help students build this foundational knowledge play an important role in closing the gap between knowing and understanding, thereby improving the ability to fulfill all the steps in Bloom's Taxonomy, all the way to *Create*, and granting instructors and students a way to achieve their higher-level learning objectives that encapsulate a high-quality university-level education.

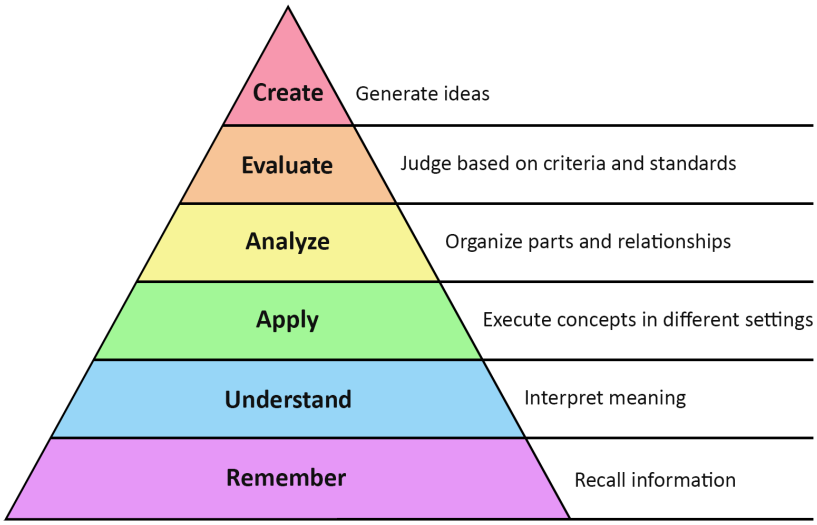


Figure 2: Bloom's Taxonomy [3] [4]

2.3 Mnemonics for Foundational Knowledge in Education

Empirical research has shown the efficacy of using mnemonic strategies to promote short- or long-term recall, or the *Remembering* level of Bloom's Taxonomy [16] [44]. Mnemonic techniques, such as acronyms and acrostics, reduce cognitive load by chunking material and creating long-lasting associative links in long-term memory, which improves the efficiency and reliability of the recall of complex knowledge [16].

Mnemonics have been applied in pedagogical settings, such as classrooms, to discover their positive

impact on knowledge retention. A study documents that these techniques provide a framework to help students convert arbitrary information into relevant and easily retrievable ideas [45]. This is a valuable strategy for memory-intensive undergraduate courses, where mnemonics can help manage the learning of the overwhelming amount of content. Literature has demonstrated that mnemonic use leads to better recall compared to passive study methods [46] [16]. By creating meaningful connections between new information and existing knowledge, mnemonics engage elaborative rehearsal, which improves long-term memory. In this way, encoding information through mnemonics is not just repetition, but a meaningful processing strategy that facilitates retention.

However, the existing research focuses on *mnemonic-based instruction* rather than *mnemonic-tool integration*. Studies often evaluate the results of students being taught or provided with mnemonics for a specific set of information [47] [48] [44]. There is less exploration on how to empower students to create, organize, and maintain their own mnemonic devices throughout their academic lives. This gap exposes the lack of studies about the practical adaptability of mnemonic strategies and highlights an opportunity to develop technological support to facilitate the reshaping of a taught method to a self-sustained learning habit.

2.4 Digitization of Mnemonics-Based Learning Tools

The cognitive theory behind mnemonics usage in pedagogical contexts is robust. However, their practical application in students' studying strategies is often unsystematic and disorganized. A recent review explored the emergence of interactive tools designed and developed to facilitate mnemonic creation [1].

Table 1 outlines the target subjects of the studies. In majority of the experiments, language learning is the main focus (5/9, 55.6%), including learning kanji and German. Other target subjects were mainly related to healthcare and legal English terms while a minority of studies focus on miscellaneous themes [49] [50] [51]. Some studies did not specify specific themes [52]. This distribution suggests that mnemonic-based tools are most frequently used in language learning, likely because vocabulary and character learning involve learning large amounts of arbitrary information that benefit from structured encoding strategies [53]. The use of mnemonic-based tools in domains such as healthcare terminology indicates the applicability of these type of tools to specialized or technical content, demonstrating the versatility of mnemonic-based interventions across different subject areas.

Table 1: Target subjects of existing mnemonic-based tools [1]

Target Subject	**Papers**
Language learning	Lee and Lan [54]
	Lin and Mase [55]
	Agnes and Srinivasan [56]
	Keehl and Melcer [57]
	Savva et al. [58]
Healthcare	Tsuruoka et al. [49]
Legal English terms	Luczak [50]
Miscellaneous	Mountstephens [51]
Not specified	Mountstephens [52]

Table 2 shows the evaluation period after which users were tested on their learning from when they used the tool. Most papers assessed users' learning after a short-term period, either immediately after learning (4/9, 44.4%) or after 24 hours of the experiment (1/9, 11.1%) [54] [51] [57] [58]. There is a scarcity of experiments that discover the long-term retention of users' learning. The review found that 33.3% (3/9) of the papers assessed learning after one week or more, while another 33.3% (3/9) did not specify the duration [55, 51, 56, 49, 52, 50]. Evidence from mnemonic-based learning research suggests that mnemonic strategies can significantly improve long-term retention compared to simple study methods, such as using keyword mnemonics to improve recall even one week after learning than control groups that relied on repetition or reading-only study [59] [60]. These findings imply that, to truly assess learning efficacy, longer-term follow-up beyond 24 hours should be included.

Table 2: Evaluation of users' learning after using mnemonic-based interactive tools [1]

Evaluation Time	**Papers**
Immediately after learning	Lee and Lan [54]
	Mountstephens [51]
	Keehl and Melcer [57]
	Savva et al. [58]
24 hours after learning	Keehl and Melcer [57]
1 week after learning or more	Lin and Mase [55]
	Mountstephens [51]
	Agnes and Srinivasan [56]
Not specified	Tsuruoka et al. [49]
	Mountstephens [52]
	Luczak [50]

3 System Design and Implementation

This section elaborates on the process of developing and designing the interactive mnemonic-based web application.

3.1 SANKOFA Toolkit

3.1.1 Philosophy

The term *Sankofa* originates from the Twi language in Ghana and means "to go back" [61]. Oyibo applies this principle to learning by emphasizing the value of revisiting material to strengthen understanding and improve recall [38]. In the context of education and learning, Oyibo coins SANKOFA as an acronym which stands for *Save All New Knowledge Optimally and Fetch Accurately* [38]. The knowledge acquisition part of the SANKOFA approach is further explained in the form of the SAVE Tool in Section 3.2.

3.1.2 Design

The applications in the SANKOFA Toolkit were designed using the iterative design thinking process, first introduced by Plattner et al., and further adapted by the Hasso Plattner Institute of Design at Stanford as shown in Figure 3 [5] [6]. At the start of the iterative process, we empathized with students studying memory-extensive courses that contain long lists of information to memorize. We realized that learning all the information in order without overloading cognitive capacity is difficult.

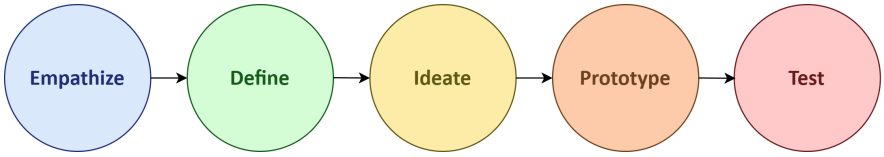


Figure 3: Design Thinking Process [5] [6]

The problem was defined as developing a toolkit that utilizes effective memory techniques to aid students in learning. During ideation, we set out to design an interactive tool that helps create and save mnemonics. We conducted a pre-experiment survey to discover features that potential users may want in a mnemonics-creation tool (further discussed in Section 4.2.1 & Section 5.1). The prototyping phase involved designing multiple wireframes and low-fidelity prototypes. These prototypes were scrutinized by the researchers to ensure that the features were accurately implemented and design principles were being followed. If any user need was not addressed, we would come up with new features to add to the prototype. After the iterative prototyping through 2 iterations, we evaluated the usability of the high fidelity prototypes using task-based testing to make sure the features were working as required. Upon the completion of testing, the SAVE Tool was developed.

3.2 SAVE Tool

The SAVE Tool is an interactive web application used to create, save, and maintain mnemonics. The "SAVE" term itself is an acronym, proposed by Oyibo [38], which stands for *Select*, *Associate*, *Visualize*, and *Elaborate*, using the first four principles from the Principles of Memory [62]. The SAVE Tool has multiple components, including My Toolbox, which is where users can view all their created mnemonics, grouped into topics, and Workbench, where users can create and edit mnemonics.

3.2.1 My Toolbox

My Toolbox is a sandbox component where every user can view the topics of a course. Under each topic, they can view the mnemonics they have created. If they want to create a new mnemonic, they can click on the Create Mnemonic button and choose a topic they want to build it for. They are then taken to the Workbench.

3.2.2 Workbench

Workbench is the component where users can create or edit mnemonics. To create a mnemonic, first, they have to enter the target topic, which is the name of the topic of interest. Then, they upload the image of a slide that contains the target topic and information they are trying to learn. They enter the target information, which is the text or terms they are learning. After that, they select the type of mnemonic they want to create: acronym or acrostic. An acronym is a mnemonic formed by using the first letter of each word in a phrase to create a new word while an acrostic is a mnemonic sentence with each word or phrase, particularly the first letter, corresponding to a word or phrase in the target information. Then, they upload an image that represents the mnemonic. Next, they enter each mnemonic cue, which is the mnemonic letter(s), word, or phrase that maps to the target word or phrase. For each mnemonic cue, they add the corresponding word or phrase in the target information and they upload an image that represents the target term. This step is repeated for each term in the mnemonic. Then, the user enters the verbal cue, or conceptual connection, which is their explanation as to how the mnemonic is connected or linked to the target topic. Lastly, they enter tidbits, which are key points associated with the target topic or information that can foster remembering or understanding. Once they have completed filling out all the text boxes in the Workbench, they click on the Save button and their mnemonic is created. They can then view the mnemonic they created by navigating to *My Toolbox* and selecting the topic they selected before entering the Workbench.

3.2.3 Implementation Details

The wireframing and prototyping process was done on Figma. The tool itself was developed using Next.js v15.1.5 and technologies including JavaScript, HTML5, and Tailwind CSS. Supabase, a Postgres-based platform, was used for the backend, specifically the database, user authentication, and file storage. The webpage was hosted on Netlify.

4 Methodology

This section discusses the methodology used to evaluate and validate the SAVE Tool in a pedagogical context.

4.1 Experiment Design

To motivate and guide the evaluation and validation of the SAVE Tool, this study adopts the experiment design outlined by Oyibo [38].

4.1.1 Participants

Students at York University were recruited as participants starting from September 2025 to the middle of October 2025. Participants were recruited from York University using self-selection sampling (posters, mailing lists), convenience sampling (students readily available on campus), and snowball sampling (word of mouth). For partaking in the study, participants were remunerated with $50 CAD either in cash or through Interac e-Transfer. Prior to the experiment, participants filled out a screening survey (see Appendix B.1) provided in the recruitment message for the study. Upon completing the screening survey, participants were asked to choose a session based on their availability. We did not establish strict inclusion criteria and decided to include all participants to ensure a more varied sample.

As of mid-October 2025, 130 participants filled out the screening survey and 47 participants booked sessions and participated in the study. Participants were randomly assigned to the Control (C) or SAVE (S) condition, with the total sample size (n = 45) determined according to power calculations from Oyibo [38]. Based on a first-come, first-served basis, 23 participants were assigned to the C group while 24 were in the S group. Participants were anonymized using group-specific codes. The C group participants were assigned identifiers of the form *C##*, where *##* denotes a two-digit number, and the S group participants were assigned identifiers of the form *S##*. These codes were used for data cleaning, tracking responses across sessions, and ensuring confidentiality during analysis. Three participants from the S group did not return for Part 2 of the experiment, and mean substitution was used to impute their missing Part 2 responses. After inspecting the data, 2 participants were excluded from the data analysis. Participant C02 was removed due to suspicion of using external online resources during the quizzes, indicated by an unusually high number of completely correct, sequential answers while Participant S22 was excluded mistakenly based on extremely low quiz scores when Participant S21 was meant to be removed. These exclusions resulted in 22 participants in the C group and 23 participants in the S group. Participant demographics are presented in Appendix D.1.

4.1.2 Apparatus

The in-person study took place in the Seminar Room 102 at the Lassonde Research Center at York University, Keele campus. Four display screens were available and used to play the lecture video and PowerPoint content. Personal laptops were connected to the display screens and external speakers were utilized to ensure that the audio could be heard clearly by all participants. The participants were required to bring their own personal laptops to participate in the study and were also requested to charge their laptops in case it was difficult to connect to power outlets.

The video lecture covered 6 biology-based topics: Krebs Cycle Substrates (KS), Krebs Cycle Reactions (KR), Cranial Nerves (CN), Cranial Nerve Functions (CF), Biological Organization Levels (BL), and Biological Organization Disciplines (BD). The video lecture covered the topics in an academic lecture format using Microsoft PowerPoint slides created by Kiemute Oyibo (see Appendix C.1) and was 8 minutes long for the Control group and 10 minutes long for the SAVE group (2 minutes longer due to the addition of mnemonics at the end of the video). The training video for the SAVE Tool was 10 minutes long and instructed participants on how to create and save an acrostic mnemonic successfully (Table 3) for the Big Five Personality Trait theory by Costa and McCrae [7] using the tool (see Figure C.2.1). The voiceover for the biology-based video lecture and SAVE Tool training video was recorded by me using OBS Studio.

Table 3: Big Five Personality Traits mnemonic. Mnemonic created by Kiemute Oyibo. Licensed under CC BY-NC-SA.

Big Five Personality Traits	**Mnemonic**
Openness	Open
Conscientiousness	Container
Extraversion	Exited
Agreeableness	Algeria's
Neuroticism	Nuke

The surveys in the experiment were administered through Google Forms. Surveys include the initial research survey as discussed in Section 4.2.1 (see Appendix A), the screening survey (see Appendix B.1), the consent forms (see *Consent Form* in Appendices A and B), the quizzes (Quiz 1.1 and Quiz 1.2; Quiz 2.1 and Quiz 2.2; Quiz 3.1 and Quiz 3.2; see Appendix B.4), the demographics survey (see *Demographics Survey (Control Group)* in Appendix B.2), the UX surveys (see *UX Survey: SAVE Tool (Experimental Group)* in Appendix B.2), and the exit surveys (see *Exit Survey (Control Group)* and *Exit Survey (Experimental Group)* in Appendix B.3). The quiz was divided into 2 parts, namely *Recall* and *Recollection*. The description at the end of Part 1 of the quiz contained the link to Part 2 of the quiz. The user experience scale for the UX survey was established using the HUED CUP taxonomy introduced by Oyibo [63] and the questions were adapted from the UTAUT constructs elaborated by Oyibo [64] as shown in Table 4.

Table 4: Perceived UX variables and questions from UX survey

Variable	**Questions**
Perceived Ease of Use	I find the steps to use the SAVE Tool easy to follow
	The SAVE Tool was confusing to use
Perceived Usefulness	I found the SAVE Tool useful to learn memory-intensive course content
	The SAVE Tool will help me to prepare for memory-intensive course exams
Perceived Enjoyment	I found using the SAVE Tool enjoyable
	I did not find using the SAVE Tool fun
Perceived Trustworthiness	The SAVE Tool is trustworthy
	I think the SAVE Tool does not have my best interest in mind
Willingness to Adopt	The features of the SAVE Tool convince me to adopt it to study for a memory-intensive course exam
	The features of the SAVE Tool motivate me to use it in my future memory-intensive courses

The PowerPoint slides of the video lecture, provided to both the Control group and SAVE group, were printed out on paper. For the SAVE group, instruction manuals were provided during training to use the

SAVE Tool and studying for the quiz. The mnemonics were also printed out on paper (Figures C.1.23, C.1.24, & C.1.25). The mnemonics for KS and KR are shown in Table 5 (Krebs Cycle substrates and reactions adapted from [65]), CN and CF in Table 6 (the mnemonic for CF is adapted from the popular mnemonic, *"Some Say Marry Money, But My Brother Says Big Brains Matter More"* in the gray literature), and BL and BD in Table 7 (biological organization levels and disciplines adapted from [66]). In the mnemonics for KS and KR, each reaction gets the corresponding substrate and produces the next substrate. For example, *Condensation* uses *Acetyl CoA* as well as *Oxaloacetate* and results in *Citrate*, *Isomerization* converts *Citrate* into *Isocitrate*, and so on. This cycle is repeated until *Oxaloacetate* is formed from the *Oxidation* of *Malate* and the cycle from the *Condensation* reaction begins again.

Table 5: Krebs Cycle Substrates (KS) and Reactions (KR) mnemonics. Mnemonics created by Kiemute Oyibo. Licensed under CC BY-NC-SA.

Substrate	**Mnemonic**	**Reaction**	**Mnemonic**
Acetyl CoA	Acetic	Condensation	Condemned
Citrate	City	Isomerization	Isometrician ("exerciser")
Isocitrate	Isobel's	Oxidative decarboxylation (Oxidation)	Oxton ("name")
Ketoglutarate	Kettle gulttonously	Oxidative decarboxylation (Oxidation)	Overloaded
Succinyl CoA	Succintly	Phosphorylation	Pharaoh's
Succinate	Sucks	Oxidation	Ox (with)
Fumarate	Fumy	Hydration	Hydraulic
Malate	Malt	Oxidation	Oxide
Oxaloacetate	Oxaloacetic		

Table 6: Cranial Nerves (CN) and Functions (CF) mnemonics. Mnemonics created by Kiemute Oyibo. Licensed under CC BY-NC-SA.

Nerves	**Mnemonic**	**Functions**	**Mnemonic**
Olfactory	Oldfactory	Sensory	Seers
Optic	Optician's	Sensory	Say
Oculomotor	Oculi ("eyes")	Motor	Move
Trochlear	Trouble	Motor	Motor
Trigeminal	Trigonometrically	Both	But
Abducens	Abductor's ("Ab doctor's")	Motor	Motorist
Facial	Facial	Both	Bosses
Vestibulocochlear	Vestibule ("eyes")	Sensory	Say
Glossopharyngeal	Glossing pharyngeally ("near the neck")	Both	Big
Vagus	Vagina	Both	Brain
Accessory	Accessory	Motor	Matters
Hypoglossal	Hypoglossal ("unshiny")	Motor	Most

Table 7: Biological Organization Levels (BL) and Disciplines (BD) mnemonics. Mnemonics created by Kiemute Oyibo. Licensed under CC BY-NC-SA.

Levels	Mnemonic	Disciplines	Mnemonic
Atom	At	Chemistry	Chemist
Molecule	Moldova's ("country between Romania and Ukraine")	Molecular Biology	Mollahs ("experts")
Organelle	Original	Cellular Biology (Cytology)	Callout
Cell	Cell	Cellular Biology (Cytology)	Cellular
Tissue	Tutsi ("Rwandan ethnic group")	Histology	Historians
Organ	Organized	Anatomy	Analyzing
Organ System	Organic	Physiology	Physical
Organism	Orgy	Biology	Bones
Population	Popular	Population Biology	Populating
Community	Commanding	Community Ecology	Compton ("Hip-hop city in California")
Ecosystem	Economic	Ecology	Echoing
Biosphere	Boom	Biogeography	Bigotry

4.1.3 Design

This experiment utilized a 2 × 3 mixed-methods study design incorporating a between-subjects factor and a within-subjects factor. The between-subjects independent variable was condition (*cond*), referring to the educational tool used to study the lecture content and prepare for the quizzes:

- **Control Group (C):** Microsoft PowerPoint slides
- **Experimental or SAVE Group (S):** SAVE Tool with researcher-created mnemonics

The within-subjects independent variable was time (*time*). The quiz was conducted at three different time points with each quiz consisting of two separate parts for *Recall* and *Recognition*:

- **Time 1 (T1)**, consisting of a quiz divided into two parts: Quiz 1.1 (Recall) and Quiz 1.2 (Recognition)
- **Time 2 (T2)**, consisting of a quiz divided into two parts: Quiz 2.1 (Recall) and Quiz 2.2 (Recognition)
- **Time 3 (T3)**, consisting of a quiz divided into two parts: Quiz 3.1 (Recall) and Quiz 3.2 (Recognition)

Thus, the within-subjects factor included three repeated trials (1 × 3 design). The primary dependent variable was participants' performance, measured through their quiz scores. Performance was evaluated across two cognitive tasks (*task*):

- **Recall (RCL):** Participants listed the terms from memory based on the target information. This represents the *Remember* level from Bloom's Taxonomy.
- **Recognition (RCG):** Participants answered multiple choice questions that assessed their comprehension of the target topic (i.e., ideas and concepts). This represents the *Understand* level from Bloom's Taxonomy.

Biology topics were selected for this study because introductory biology courses are naturally memory-intensive, often requiring students to memorize numerous facts, classifications, and specialized terminology. Prior research has shown that assessment items in such courses predominantly focus on lower-order cognitive skills, emphasizing factual recall over higher-order reasoning [41]. This makes biology an ideal domain

for testing mnemonics-based strategies, which aim to support memory and promote connections between lower-order and higher-order learning. Topics were also chosen to strike a balance in difficulty, making sure they were neither too easy, which could produce ceiling effects, nor too challenging, which could hinder meaningful engagement with the content, mnemonics, and SAVE Tool. The quiz questions were generated using ChatGPT (OpenAI), after which they were reviewed and refined by Kiemute Oyibo and me for accuracy and clarity.

Across the three time points, participants completed quizzes designed to capture different stages of memory performance (see Appendix B.4). Time 1 (T1) represents the first quiz, which took place in Part 1 of the experiment and measured participants' *immediate memory* following their initial exposure to the learning material, consistent with memory-based research demonstrating rapid recall immediately after encoding [2] [67]. This assessment consisted of two components: Quiz 1.1 (recall) and Quiz 1.2 (recognition). Time 2 (T2), representing the second quiz, was administered one week later at the beginning of Part 2 to assess *delayed recall*, a measure of longer-term retention after a period without rehearsal, aligning with well-established forgetting-curve research [68]. T2 also included two components: Quiz 2.1 (recall) and Quiz 2.2 (recognition). Time 3 (T3), which represents the third and final quiz, occurred after a 15-minute revision period in Part 2 and evaluated *revision-driven memory*, reflecting immediate post-review retrieval strengthened by restudy and effortful retrieval effects [25] [69]. Similar to the earlier assessments, T3 comprised Quiz 3.1 (recall) and Quiz 3.2 (recognition).

4.2 Experiment Procedure

4.2.1 Pre-Design Survey

A survey was distributed to the York University student body to assess students' interest in using mnemonics for studying academic course content, as well as their desired features in a tool that supports mnemonic creation (see Appendix A). Participants were remunerated with $10 CAD for completing the survey. The survey was divided into 3 parts. Part 1 was about studying techniques that the participants currently use and if they ever used mnemonics before, consisting of questions adapted from the *Memory Principles Inventory* [62]. At the end of Part 1, participants provided their demographic information. In Parts 2 and 3, participants created acrostic mnemonics for types of interview questions [70] and Don Norman's design principles [71] respectively. 123 participants filled out Part 1 while 102 participants completed Parts 2 and 3. The discrepancy in participant numbers likely resulted from using separate Google Forms for each part. The link to the next part was included in the description of the preceding form, so participants who overlooked the instructions may have missed or skipped the subsequent sections.

4.2.2 Experiment: Part 1

Prior to scheduling the experiment sessions for the study, the participants were asked to fill out a screening survey to note whether they studied biology at an undergraduate or higher education level. After that, they received an email to select a scheduled session that suited their availability. The email also contained details about the session such as the location address and duration of the session. The procedures for the Control (C)

and SAVE (S) groups are described below. At the end of Part 1, the participants from both groups were asked to schedule a session for Part 2 after 1 week as per their convenience. The steps of Part 1 of the experiment are shown in the Figure 4.

Control group (C): Part 1 of the experiment was an in-person, experimental study. The experiment protocol for Part 1 is shown in Figure 4. Participants were required to come to the Seminar Room 102 in the Lassonde Research Center with their personal laptops. The experiment session began with an introduction of the study and the researchers. Participants were sent an email with a link to the consent form of the study. After receiving the participants' filled consent forms, the 8 minute long video lecture was played on the display screen. Then, participants were given the physical version of the slides that were used in the video lecture. They were told to prepare the lecture content for 45 minutes. Once 45 minutes passed, the PowerPoint slides were collected from the participants and the participants were given a 5 minute break to relax. After the 5 minute break, the participants were sent an email containing the link to the quiz on Google Forms. The participants were instructed that the quiz had 2 parts and the link to the 2nd part was provided at the end of the 1st part. After completing the quiz, the participants were asked to provide their demographic information through a demographic survey which was sent to them via email.

Experimental or SAVE group (S): Similar to the Control group, Part 1 took place in person in the Seminar Room 102 in the Lassonde Research Center with the participants using their personal laptops. They were introduced to the study and provided a consent form to fill out and sign. After that, the participants were given training on how to use the SAVE Tool. In the first step of training, they were shown a 10 minute video to show how to create and save a mnemonic using the SAVE Tool. Then, they were given credentials printed on paper as well as a physical copy of the mnemonic and were given 10 minutes to log in to the SANKOFA website and create and save the mnemonic as displayed in the video. Next, they were shown the video lecture which was 10 minutes long due to the mnemonics provided at the end of the video to help them learn the taught content. The participants were then given 10 minutes to use the printed PowerPoint slides to learn the content, after which the slides were collected from them. Then they used the SAVE Tool to edit already created mnemonics. They would enter the mnemonic cues and transformed target information (keywords) manually so that they would be engaging with the content to be learned. After 35 minutes, the participants were given a 5 minute break. Next, they were given the link to the quiz via email which they had to complete in 45 minutes. Similar to the C group, the quiz had 2 parts and the link to the 2nd part was provided at the end of the 1st part. After the 45 minutes passed or when all the participants completed the quiz, whichever occurred first, the participants were given a link to a UX survey to help gauge their user experience while using the SAVE Tool.

4.2.3 Experiment: Part 2

Participants returned 1 week later (as scheduled by themselves) to complete Part 2 of the experiment. Both groups were introduced to Part 2 of the study. According to the recruitment material, Part 2 was said to be a shorter version of Part 1 but with another subject. However, Part 2 involved taking the same quiz again,

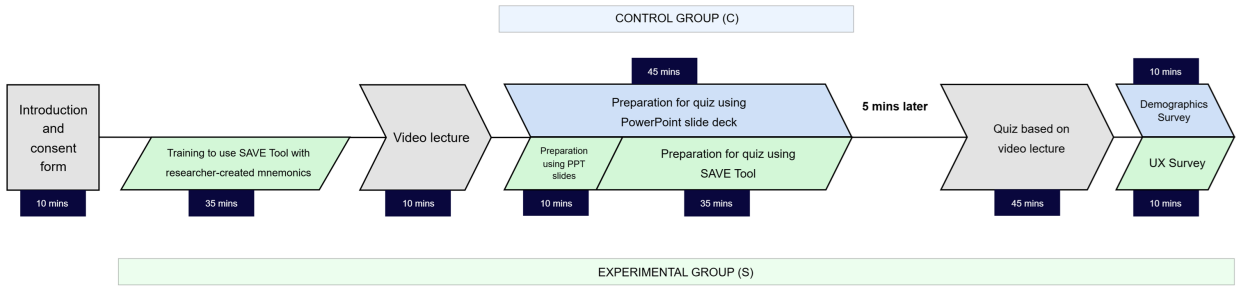


Figure 4: Experiment protocol of Experiment: Part 1

preparing using the educational tool based on the group, taking the quiz a third time, and lastly, filling out exit surveys. The participants were debriefed about the deception and lack of details provided about Part 2 during the introduction. The consent form for this part of the experiment also included the debriefing form. The experiment protocol for Part 2 is shown in Figure 5.

Control group (C): First, the participants were given the introduction to Part 2 of the study. Then, they completed the quiz within 45 minutes. For the C group participants, after they completed the quiz, they were asked to revise for the quiz using the printed out PowerPoint slides for 15 minutes. After revision, the participants attempted the quiz again within 45 minutes. Then, they filled out the exit survey and were provided with $50 CAD remuneration.

Experimental or SAVE group (S): The participants were first introduced to Part 2 of the study. They attempted the quiz within 45 minutes and then revised for the quiz using the SAVE Tool for 15 minutes. After that, the participants completed the quiz again within 45 minutes. Lastly, they completed the exit survey that included demographics and questions about the UX of the SAVE Tool.

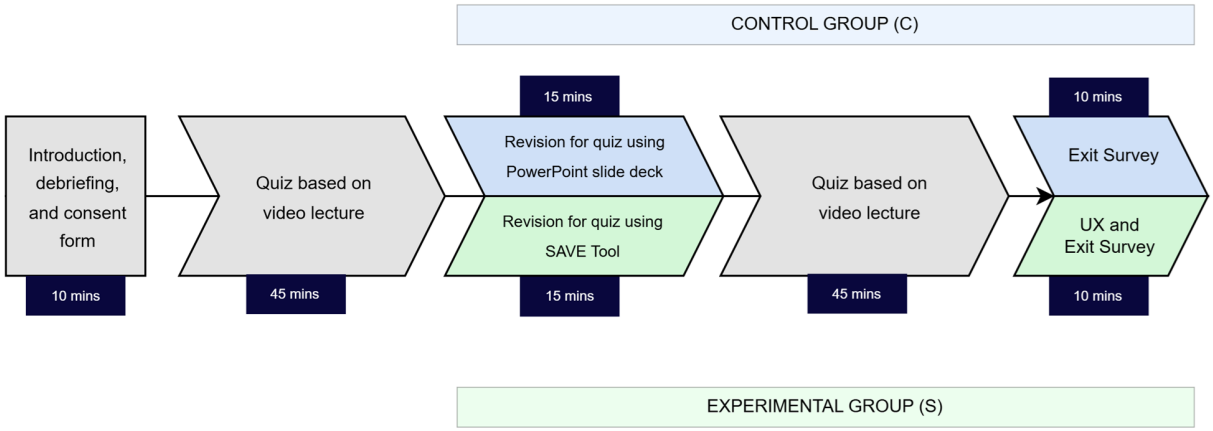


Figure 5: Experiment protocol of Experiment: Part 2

5 Results

This section presents the results of the pre-design and user experience (UX) surveys and the cognitive experiments conducted for this thesis.

5.1 Pre-Design Survey

After collecting data for the pre-design survey (see Appendix A), the answers from the question, *"What feature(s) would you like the tool that helps you create your own mnemonics to have?"* were arranged in a Google Sheet. Kingson Fung and I performed thematic analysis on the features suggested by the participants. We then calculated the Cohen's Kappa for inter-rater reliability [72] and resolved disagreements. The coding resulted in categories such as personalization, recommendations, and flexibility as listed in Table 8. Some categories related to the types of mnemonics participants wanted to create, while majority were relevant to the preferred features of the mnemonics-creation tool. Mnemonic-based categories described features of the mnemonics themselves. Relevance to topic referred to mnemonics directly linked to course content. Meaningfulness captured mnemonics with clear semantic or personal significance while humor described mnemonics that included amusing or playful elements to increase distinctiveness. On the other hand, the SAVE-based categories reflected the mnemonics-based tool features participants indicated as desirable. Recommendations referred to system-provided guidance for creating mnemonics. Visuals captured the inclusion of images or graphical support. Customization referred to user-controlled adjustments to the tool's interface or outputs, while personalization reflected the system's adaptation of content or support to individual learner preferences. Flexibility captured the ability to create, revise, or compare multiple mnemonics. While designing the features of the SAVE Tool, these categories were used to motivate the requirements analysis of the application and thus, drove the implementation of the features of the SAVE Tool, *My Toolbox* and *Workbench*.

Table 8: Thematic analysis of participant comments in pre-design survey

Type	**Category**	**Count (%)**	**Cohen's Kappa**
Mnemonic-Based	Relevance to Topic	6 (4.91%)	0.6541
	Meaningfulness	6 (4.91%)	1.0000
	Humor	5 (4.10%)	0.7421
SAVE-Based	Recommendations	29 (23.60%)	0.6523
	Visuals	24 (19.51%)	0.6889
	Customization	17 (13.82%)	0.4602
	AI-generated content	10 (8.13%)	0.6004
	Ease of Use	8 (6.50%)	0.8486
	Flexibility	8 (6.50%)	0.4771
	Multiple mnemonics	7 (5.69%)	0.6474
	Personalization	6 (4.88%)	0.4841

5.2 Experiment

Before presenting the analysis results, the following subsubsections detail the scoring of participant responses and the statistical analysis setup in R.

5.2.1 Data Analysis Setup

Response scoring procedure: The data from the experiments were gathered and organized for each participant and imported into a Google Sheet to be given scores by the researchers. The recognition quizzes had explicit answers and did not require manual scoring. Meanwhile, the recall quizzes prompted participants to enter values. The answers were cleaned and formatted by Kingson Fung and me. We independently assigned scores, calculated inter-rater reliability using Cohen's Kappa [72], and resolved any disagreements. For the recall task, the goal was to examine how well the participants were able to remember and reconstruct target information encoded using mnemonics. Oyibo [73] proposed (1) the use of orthographic similarity to evaluate participants' responses to recall questions such as *"List the cranial nerves in order"* to ensure objectivity to avoid dealing with semantics and the examiner's subjective judgment, and (2) setting predefined rules to clean the data i.e., participants' responses. Orthographic similarity [74] refers to how closely a given response resembles a target word based on allowable letter changes. In this study, we utilized orthographic similarity using Levenshtein distance [75], which calculates the minimum number of edits, including insertions, deletions or substitutions, required to transfer a participant's response into the correct answer . Without such an objective metric, examiners would need to assign partial-credit scores based on subjective judgments of correctness. For instance, for the response *"oculomoter"* (target: *"oculomotor"*, examiner A might assign 0.7, examiner B might give 0.8, and examiner C might consider it a simple typo and award full scores. Using Levenshtein distance eliminates this variability: the more edits needed to convert the response into the correct word, the lower the orthographic similarity score. Together, these approaches standardize scoring, reduce subjective interpretation, and ensure more reliable evaluation of participant responses. The rules for scoring the data prior to carrying out orthography similarity computation include the following:

1. The orders of responses in each pair of topics should match. For example, if the response for the first cranial nerve is "Olfactory", the response for the first cranial nerve function must be "Sensory". If not, the response receives a 0.

2. If the response contains a word or part of a word that matches a part of the correct answer, whether one term or phrase-based, (about 40% or at least 1 syllable), keep it as it is. For example, if the response is "Hydro" and the correct answer is "Hydration", leave the response as it is.

3. If the response is the correct answer presented in a different format, change the response to the correct answer and note that a change has been made. For example, if the response is "Sense of smell" and the correct answer is "Sensory", change the response to "Sensory" and give them a partial score of 1. This was to compensate for participants who may have misinterpreted the format of answers we were expecting. For example, for the Cranial Nerve Function responses, we expected one of the terms as a valid response: *Sensory*, *Motor*, or *Both*.

4. If the response is a completely different term or phrase compared to the answer, the response is given a 0. For example, if the response is "Animal" and the correct answer is "Organism", the response receives a 0.

Statistical analysis: Data was analyzed and visualized using R. To visualize means and percentages of data via bar charts, we used *ggplot2* [76]. Repeated measures analysis of variance (RMANOVA) and Aligned Rank Transform (ART) were carried out using *ARTool* [77]. ART-ANOVA was required for non-parametric RMANOVAs [78]. ART-ANOVA is used for data that is not normally distributed and can handle multiple independent variables, interaction effects, and repeated measures. If the traditional ANOVA assumptions are violated, such as normality and independence, ART-ANOVA is recommended as a helpful approach [78].

The following subsubsections focus on topic familiarity, the overall means observed for the performance scores, and the results of conducting RMANOVAs. Pairwise comparisons between topics were conducted using Tukey's method with family-wise error correction to control for the increased risk of false positives when performing multiple comparisons, ensuring that significant differences reflect true effects rather than chance.

5.2.2 Topic Familiarity

Responses from the exit surveys (see Appendix B.3) were used to determine topic familiarity scores from 1 (Strongly Disagree) to 7 (Strongly Agree). Figure 6 shows that BL and BD had high familiarity scores with those of C less than 3.50 and S greater than 3.50 while CF and CN had lower familiarity scores, between 2.00 and 2.50 for both groups, and KR and KS had the lowest familiarity scores, with those of C between 2.00 and 2.50 and S less than 2.00.

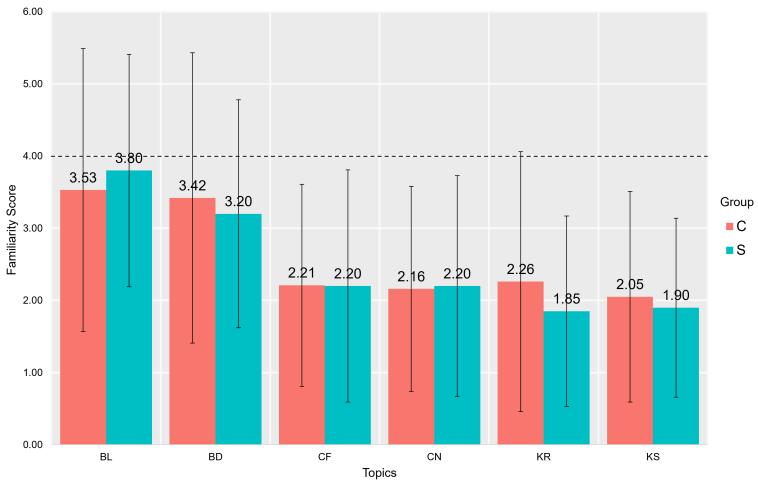


Figure 6: Topic familiarity scores derived from mean familiarity ratings from exit surveys (see *Exit Survey* in Appendix B.3) across topics for C (Control group; n = 22) and S (SAVE group; n = 23) participants. The dotted line denotes the neutral score (4.00) and the error bars represent the standard deviations. Scores: 1 = Strongly Disagree, 2 = Disagree, 3 = Somewhat Disagree, 4 = Neutral, 5 = Somewhat Agree, 6 = Agree, 7 = Strongly Agree. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

5.2.3 Cognitive Performance

Descriptive statistics: The descriptive statistics for both groups is shown in Table 9. Overall, the statistics show similar performance patterns between the C and S groups across all time points. Both groups exhibit relatively wide score ranges, indicating considerable variability in recall performance. The skewness and kurtosis values suggest that several distributions deviate from normality, supporting the need to use non-parametric analyses. Across time points, mean scores generally increase from T1 to T3, reflecting improved recall over time in both groups.

Table 9: Overall descriptive statistics. Groups: C = Control, S = SAVE. Time: 1 = T1, 2 = T2, 3 = T3. Tasks: RCL = recall, RCG = recognition.

Group	n	Mean	SD	Median	Min	Max	Range	Skew	Kurtosis	SE	Time	Task
C	22	0.45	0.23	0.41	0.16	0.87	0.70	0.30	-1.42	0.05	1	RCL
S	23	0.52	0.20	0.51	0.10	0.95	0.86	0.12	-0.46	0.04	1	RCL
C	22	0.29	0.22	0.32	0.00	0.65	0.65	0.16	-1.47	0.05	2	RCL
S	23	0.30	0.23	0.27	0.00	0.76	0.76	0.67	-0.85	0.05	2	RCL
C	22	0.64	0.24	0.58	0.24	0.99	0.75	0.06	-1.59	0.05	3	RCL
S	23	0.75	0.18	0.75	0.27	0.99	0.72	-0.69	0.02	0.04	3	RCL
C	22	0.62	0.22	0.62	0.29	1.00	0.71	-0.09	-1.29	0.05	1	RCG
S	23	0.64	0.20	0.67	0.29	0.96	0.67	-0.09	-1.41	0.04	1	RCG
C	22	0.61	0.19	0.60	0.25	0.92	0.67	0.04	-1.13	0.04	2	RCG
S	23	0.57	0.17	0.57	0.29	1.00	0.71	0.46	-0.21	0.04	2	RCG
C	22	0.68	0.22	0.67	0.33	1.00	0.67	0.07	-1.37	0.05	3	RCG
S	23	0.71	0.19	0.71	0.21	1.00	0.79	-0.75	0.23	0.04	3	RCG

Overall means: Across the three time points, representing when the quizzes were conducted, Figure 7 shows that the Control (C) and SAVE (S) groups had highly similar recall performance patterns for all of the topics. Time 1 depicted both groups having moderate accuracy across all the categories with minor item-level differences with the S group having insignificantly higher scores. At Time 2, there is a decline in performance for both groups. At Time 3, performance increased for both groups substantially. Overall, the graphs indicate a significant main effect of time but less meaningful condition effect.

Accuracy for the recognition (RCG) task for the C and S groups across topics and time is shown in Figure 8. At Time 1, both groups showed similar levels of performance in all topics with insignificant group differences. Akin to Time 2 in the recall (RCL) task, there was a general decrease in accuracy for both groups at Time 2 for RCG, followed by an increase at Time 3, showcasing a consistent pattern between conditions. When averaged across the three time points, overall performance remained similar between the C and S groups for each topic.

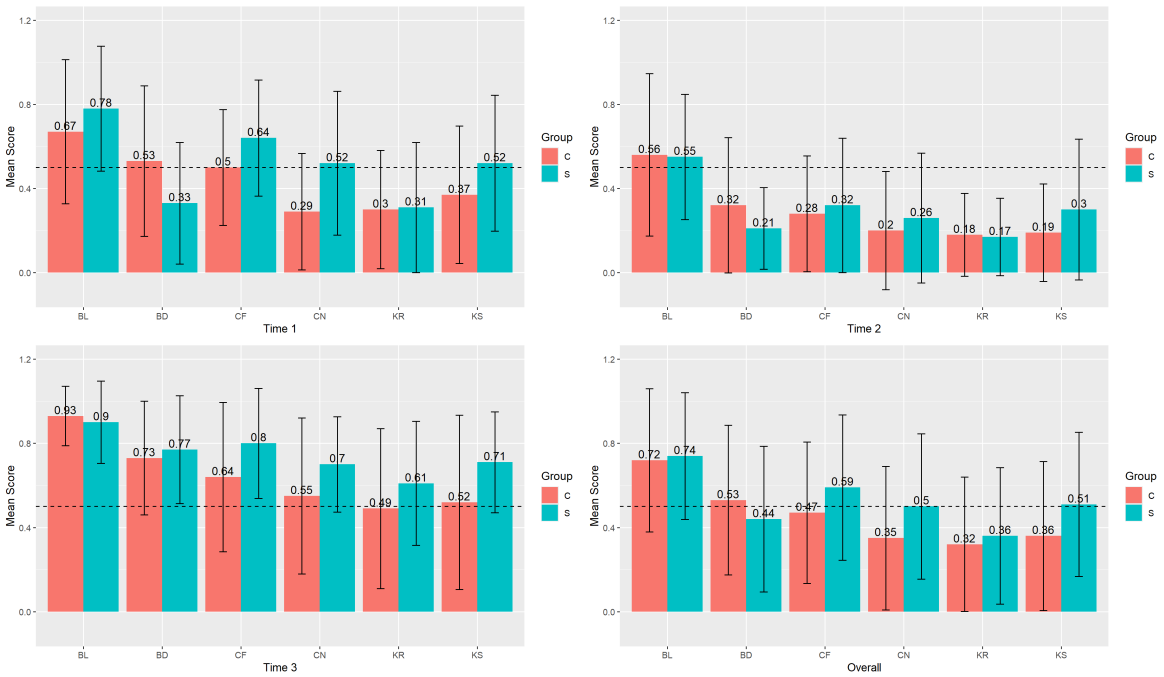


Figure 7: Average remembering (recall) scores for each topic across the three time points. The dotted line indicates the overall mean score, and error bars show standard deviations. Group labels: C = Control, S = SAVE. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

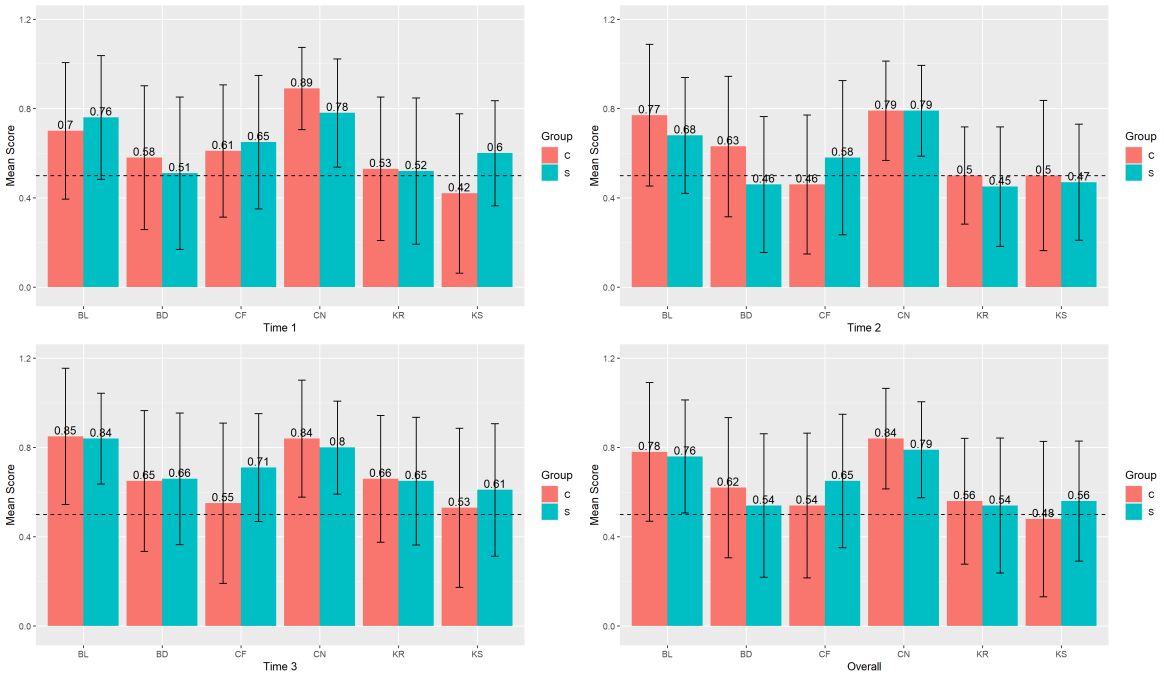


Figure 8: Average understanding (recognition) scores for each topic across the three time points. The dotted line indicates the overall mean score, and error bars show standard deviations. Group labels: C = Control, S = SAVE. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

The mean scores of both groups over time for both tasks is shown in Figure 9. The mean accuracy of the S group shows a higher improvement than the C group. At Time 1, both groups perform similarly, with the S group getting higher scores, albeit with a marginally significant difference. Then, at Time 2, there is a dip in scores for both groups in both tasks. At Time 3, the S group achieves higher scores compared to the C group at a marginally significant level.

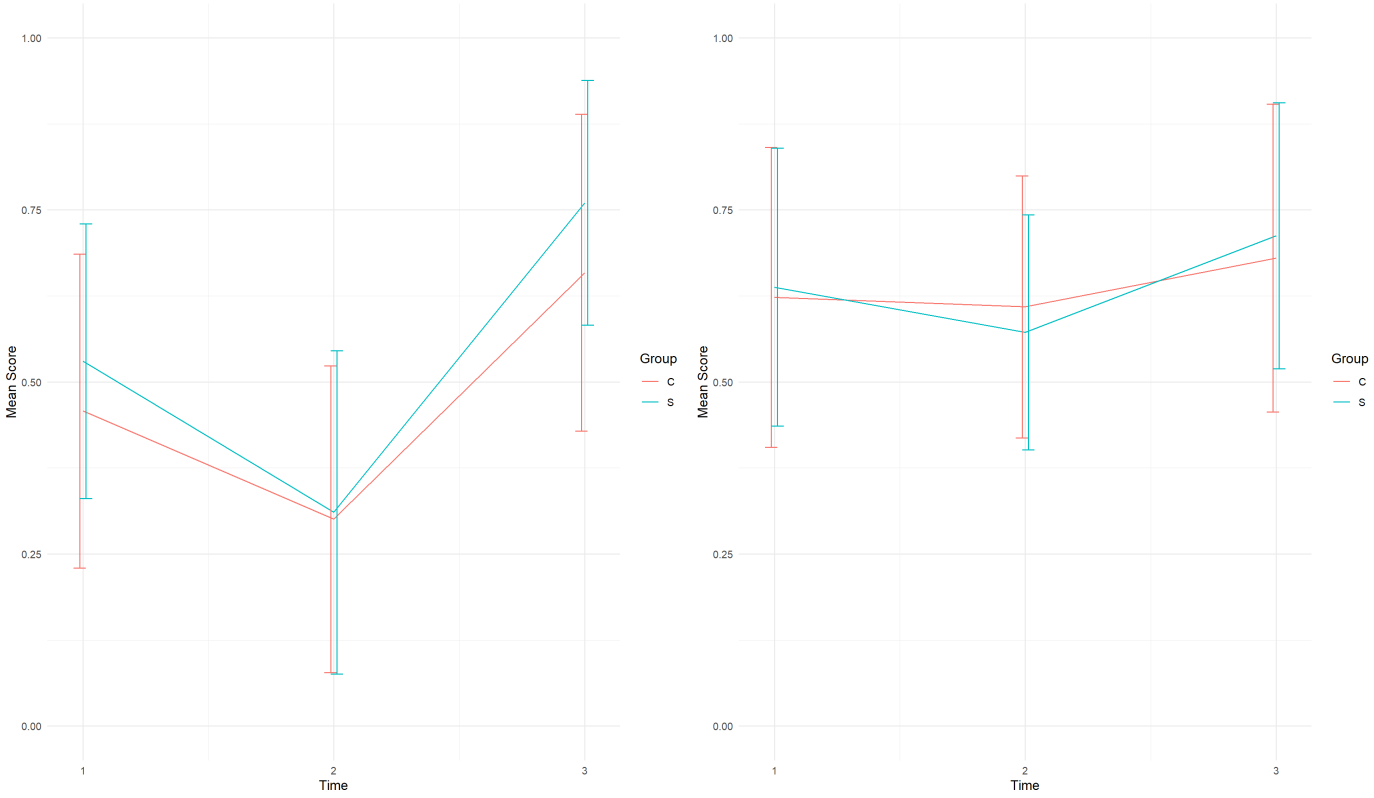


Figure 9: Overall average scores of the remembering measure (aka recall - left) and understanding measure (aka recognition - right) for the three points in time. The error bars show standard deviations. Group labels: C = Control, S = SAVE.

Overall four-way RMANOVA: The four-way RMANOVA revealed significant main effects and interactions (Table 10). There were strong main effects of cognitive task (task: recall and recognition), $F(1, 1505) = 161.66$, $p < 0.001$, topic (topics: Biological Organization Levels, Biological Organization Disciplines, Cranial Nerve Functions, Cranial Nerves, Krebs Cycle Reactions, and Krebs Cycle Substrates), $F(5, 1505) = 59.80$, $p < 0.001$, and time (time: Time 1, Time 2, and Time 3), $F(2, 1505) = 166.04$, $p < 0.001$, indicating that average performance differed across task type, topic, and time. Although the main effect of condition (condition: Control and SAVE groups) was not statistically significant, $F(1, 43) = 0.25$, $p = 0.6064$, several interaction effects emerged that are explored further. There was a significant interaction between task $\times$ condition, $F(1, 1505) = 7.20$, $p = 0.0074$, which implies that the difference between the scores in the recall and recognition tasks was based on the participants being in the C or S groups. Other significant interactions include task $\times$ topic, $F(5, 1505) = 22.38$, $p < 0.001$, condition $\times$ topic, $F(5, 1505) = 6.57$, $p < 0.001$, and task $\times$ time, $F(2, 1505) = 57.55$, $p < 0.001$, indicating the effect of topic and time as well. Higher-order

interactions were not significant, such as the three-way task × condition × topic interaction ($p = 0.0624$), meaning the combined effects of all four factors did not affect scores.

Table 10: Overall four-way RMANOVA. DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	Error	DF	DF.res	*F* value	*p*-value
Condition	PCode	1	43	0.27	0.6064
Topic	Within	5	1505	59.80	0.0000
Time	Within	2	1505	166.04	0.0000
Task	Within	1	1505	161.66	0.0000
Condition:Topic	Within	5	1505	6.57	0.0000
Condition:Time	Within	2	1505	4.87	0.0078
Topic:Time	Within	10	1505	1.55	0.1171
Condition:Task	Within	1	1505	7.20	0.0074
Topic:Task	Within	5	1505	22.38	0.0000
Time:Task	Within	2	1505	57.55	0.0000
Condition:Topic:Time	Within	10	1505	1.21	0.2788
Condition:Topic:Task	Within	5	1505	2.10	0.0624
Condition:Time:Task	Within	2	1505	0.18	0.8388
Topic:Time:Task	Within	10	1505	0.93	0.5012
Condition:Topic:Time:Task	Within	10	1505	1.13	0.3388

Overall three-way ANOVAs for recall and recognition: Three-way repeated-measures ANOVAs were conducted to examine the effects of condition, topic, and time on task, with recall (RCL) and recognition (RCG) analyzed separately as depicted in Tables 11 and 12 respectively. For both outcome variables, there was no significant effect of condition, indicating that overall performance did not differ between the C and S groups (RCL: $F(1, 43) = 1.00$, $p = 0.3222$; RCG: $F(1, 43) = 0.00$, $p = 0.9952$). In contrast, there is were significant effects of topic (RCL: $F(5, 731) = 45.53$, $p < 0.001$; RCG: $F(5, 731) = 39.74$, $p < 0.001$), implying the variation of scores across topics. Additionally, there were significant effects of time, with performance improving or changing across repeated measures (RCL: $F(2, 731) = 209.63$, $p < 0.001$; RCG: $F(2, 731) = 15.79$, $p < 0.001$). As for interactions, a condition × topic interaction was observed, indicating that topic-specific scores differed between the S and C participants (RCL: $F(5, 731) = 5.32$, $p < 0.001$; RCG: $F(5, 731) = 2.98$, $p = 0.0114$). However, no significant interactions emerged for condition × time, topic × time, and condition × topic × time, suggesting that changes across time and across topics followed similar patterns for both conditions.

5.2.4 Recall Scores

Topic-based pairwise comparison: Tukey-adjusted pairwise comparisons were conducted to examine differences in performance across topics, specifically for recall (RCL). Several contrasts displayed statistical significance, indicating variability between specific topic pairs. Biological Organization Levels (BL) consistently showed significantly higher recall than Biological Organization Disciplines (BD), Cranial Nerve Functions (CF), Cranial Nerves (CN), Krebs Cycle Reactions (KR), and Krebs Cycle Substrates (KS) (all p

Table 11: Overall three-way RMANOVA for recall based on condition, topic, and time. DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	Error	DF	DF.res	F value	p-value
Condition	PCode	1	43	1.00	0.3222
Topic	Within	5	731	45.53	0.0000
Time	Within	2	731	209.63	0.0000
Condition:Topic	Within	5	731	5.32	0.0001
Condition:Time	Within	2	731	3.58	0.0285
Topic:Time	Within	10	731	1.49	0.1392
Condition:Topic:Time	Within	10	731	1.30	0.2289

Table 12: Overall three-way RMANOVA for recognition based on condition, topic, and time. DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	Error	DF	DF.res	F value	p-value
Condition	PCode	1	43	0.00	0.9952
Topic	Within	5	731	39.74	0.0000
Time	Within	2	731	15.79	0.0000
Condition:Topic	Within	5	731	2.98	0.0114
Condition:Time	Within	2	731	2.13	0.1195
Topic:Time	Within	10	731	1.01	0.4344
Condition:Topic:Time	Within	10	731	1.00	0.4398

< 0.001; Table 13), representing the strongest-performing topic overall. CF also demonstrated significantly higher recall than CN, KS, and KR (with all $p \leq 0.0039$). In contrast, CN did not significantly differ from BD, KS, or KR, indicating relatively uniform performance across these topics. Similarly, BD and KS did not significantly differ, whereas BD showed higher recall than KR ($p < 0.001$). Finally, while comparing KS and KR, KS showed significantly greater performance than KR ($p = 0.0155$). Overall, the pattern of results highlights substantial topic-level variation, with BL and CF outperforming the other topics and KR showing lower scores.

Time-based pairwise comparison: Across the three time points, Tukey-adjusted comparisons revealed significant differences in performances for the RCL task (Table 14). Scores decreased significantly from Time 1 (T1) to Time 2 (T2; $p < 0.001$), indicating a substantial decline that occurred during the one-week delay between sessions. In contrast, scores increased significantly from Time 1 (T1) to Time 3 (T3; $p < 0.001$), and the largest difference emerged between Time 2 and Time 3, where performance improved dramatically ($p < 0.001$). The initial decline followed by a strong rebound suggests a trajectory of forgetting, then relearning with the revision period prior to Time 3 resulting in improvement in performance.

One-way ANOVA for condition and time: To further examine the interaction between condition and time suggested in the overall RMANOVA, one-way ANOVAs were conducted at each level of condition and time (Table 15). Although the SAVE (S) group showed higher recall scores than the Control (C) group at all time points, the condition effect reached significance only at Time 3 ($F(1, 268) = 4.11$, $p = 0.0437$), indicating that

Table 13: Topic-based pairwise comparison with Tukey method family-wise correction for recall. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.43	0.53	-87.84	20.57	731	-4.27	0.0003
CN – BL	0.43	0.73	-229.02	20.57	731	-11.14	0.0000
CN – BD	0.43	0.49	-48.68	20.57	731	-2.37	0.1693
CN – KS	0.43	0.44	-12.89	20.57	731	-0.63	0.9890
CN – KR	0.43	0.34	53.85	20.57	731	2.62	0.0941
CF – BL	0.53	0.73	-141.18	20.57	731	-6.87	0.0000
CF – BD	0.53	0.49	39.16	20.57	731	1.90	0.4003
CF – KS	0.53	0.44	74.95	20.57	731	3.64	0.0039
CF – KR	0.53	0.34	141.69	20.57	731	6.89	0.0000
BL – BD	0.73	0.49	180.34	20.57	731	8.77	0.0000
BL – KS	0.73	0.44	216.13	20.57	731	10.51	0.0000
BL – KR	0.73	0.34	282.87	20.57	731	13.75	0.0000
BD – KS	0.49	0.44	35.79	20.57	731	1.74	0.5054
BD – KR	0.49	0.34	102.53	20.57	731	4.99	0.0000
KS – KR	0.44	0.34	66.74	20.57	731	3.25	0.0155

Table 14: Time-based pairwise comparison with Tukey method familywise correction for recall. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
T1 – T2	0.49	0.30	136.03	13.78	731	9.87	0.0000
T1 – T3	0.49	0.70	-145.85	13.78	731	-10.59	0.0000
T2 – T3	0.30	0.70	-281.88	13.78	731	-20.46	0.0000

group differences occurred after revision. Within-group time effects were significant for both the C group ($F(2, 372) = 55.52$, $p < 0.001$) and the S group ($F(2, 389) = 105.25$, $p < 0.001$). Tukey-corrected pairwise comparisons (Tables 16 and 17) showed decrease in scores from Time 1 to Time 2 ($p < 0.001$) and increased significantly from Time 2 to Time 3 ($p < 0.001$), with Time 3 scores surpassing Time 1 ($p < 0.001$). The S group had larger effect magnitudes across all contrasts (e.g., T2 – T3 est. = -149.39 against 110.62 in the C group), suggesting a stronger rebound in recall following revision among participants using the SAVE Tool.

One-way ANOVA for condition and topic: Follow-up one-way ANOVAs were also conducted at each level of condition and topic (Table 18). The analyses revealed that for the C and S groups, recall differed significantly across topics ($F(5, 369) = 20.51$, $p < 0.001$; $F(5, 386) = 14.92$, $p < 0.001$). For each individual topic, the S group scored significantly higher than the C group for CN ($F(1, 133) = 6.08$, $p = 0.015$) and KS ($F(1, 133) = 6.07$, $p = 0.0151$), while differences for CF was marginally significant ($p = 0.0549$) and were non-significant for BL, BD, and KR. Tukey-corrected pairwise comparisons (Tables 19 and 20) were conducted and highlighted that, in the C group, CN recall was significantly lower than BL ($p < 0.001$) and BD ($p = 0.0067$), and BL recall was higher than all other topics ($p < 0.001$). Similarly, in the S group, CN recall was significantly lower than BL ($p < 0.001$), CF recall was higher than KR ($p < 0.001$), and BL scores

Table 15: One-way ANOVA based on condition and time for recall due to interaction between them in Table 11 which is not evident or significant at this level of analysis. Condition labels: C = Control, S = SAVE. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of time	T1	0.45	0.52	$F(1, 268) = 3.12$, $p = 0.0784$
	T2	0.29	0.30	$F(1, 268) = 0.43$, $p = 0.5136$
	T3	0.64	0.75	$F(1, 268) = 4.11$, $p = 0.0437$
	Time Effect	$F(2, 372) = 55.52$, $p = 0.0000$	$F(2, 389) = 105.25$, $p = 0.0000$	

Table 16: Control group's time-based pairwise comparison with Tukey correction for recall. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*-value**
T1 – T2	0.45	0.29	52.72	10.50	372	5.02	0.0000
T1 – T3	0.45	0.64	-57.89	10.50	372	-5.51	0.0000
T2 – T3	0.29	0.64	-110.62	10.50	372	-10.53	0.0000

Table 17: SAVE group's time-based pairwise comparison with Tukey correction for recall. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*-value**
T1 – T2	0.52	0.30	71.88	10.30	389	6.98	0.0000
T1 – T3	0.52	0.75	-77.52	10.30	389	-7.53	0.0000
T2 – T3	0.30	0.75	-149.39	10.30	389	-14.51	0.0000

were higher than BD, KS, and KR ($p < 0.001$). These results indicate that topic difficulty strongly influenced recall performances in both groups, with the SAVE group showing somewhat higher scores in challenging topics (CN, KS), suggesting an advantage.

Table 18: One-way ANOVA based on condition and topic for recall due to interaction between them in Table 11. Condition labels: C = Control, S = SAVE. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of topic	CN	0.35	0.50	$F(1, 133) = 6.08$, $p = 0.0150$
	CF	0.47	0.59	$F(1, 133) = 3.75$, $p = 0.0549$
	BL	0.72	0.74	$F(1, 133) = 0.00$, $p = 0.9964$
	BD	0.53	0.44	$F(1, 133) = 1.73$, $p = 0.1902$
	KS	0.36	0.51	$F(1, 133) = 6.07$, $p = 0.0151$
	KR	0.32	0.36	$F(1, 133) = 0.39$, $p = 0.5321$
	Topic Effect	$F(5, 369) = 20.51$, $p = 0.0000$	$F(5, 386) = 14.92$, $p = 0.0000$	

5.2.5 Recognition Scores

Topic-based pairwise comparison: Topic-based pairwise comparisons for recognition accuracy were conducted using Tukey's method with family-wise correction (Table 21). CN recognition was significantly higher than CF ($p < 0.001$), BD ($p < 0.001$), KS ($p < 0.001$), and KR ($p < 0.001$), indicating that participants were able to understand CN better than most of the other topics. BL recognition was significantly higher than BD ($p < 0.001$), KS ($p < 0.001$), and KR ($p < 0.001$), while CF recognition was only significantly lower than BL ($p < 0.001$) but did not differ significantly from BD, KS, or KR. Comparisons between topics like BD, KS, and KR were not significant, suggesting similar comprehension performance among these topics. Overall, the results showed that recognition accuracy varied by topic, with CN and BL being recognized most accurately.

Time-based pairwise comparison: Time-based pairwise comparison was conducted for recognition performance across the three time points using Tukey's method and family-wise correction. Unlike recall, recognition scores had a non-significant decrease from Time 1 to Time 2 ($p = 0.072$), followed by a sig-

Table 19: Control group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table 18 for recall. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*.value
CN – CF	0.35	0.47	-38.70	15.03	369	-2.58	0.1061
CN – BL	0.35	0.72	-118.23	15.03	369	-7.87	0.0000
CN – BD	0.35	0.53	-52.69	15.03	369	-3.51	0.0067
CN – KS	0.35	0.36	0.25	15.03	369	0.02	1.0000
CN – KR	0.35	0.32	8.29	15.03	369	0.55	0.9939
CF – BL	0.47	0.72	-79.53	15.03	369	-5.29	0.0000
CF – BD	0.47	0.53	-13.98	15.03	369	-0.93	0.9385
CF – KS	0.47	0.36	38.95	15.03	369	2.59	0.1019
CF – KR	0.47	0.32	46.99	15.03	369	3.13	0.0233
BL – BD	0.72	0.53	65.55	15.03	369	4.36	0.0000
BL – KS	0.72	0.36	118.48	15.03	369	7.88	0.0000
BL – KR	0.72	0.32	126.52	15.03	369	8.42	0.0000
BD – KS	0.53	0.36	52.94	15.03	369	3.52	0.0064
BD – KR	0.53	0.32	60.98	15.03	369	4.06	0.0000
KS – KR	0.36	0.32	8.04	15.03	369	0.53	0.9947

Table 20: SAVE group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table 18 for recall. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*.value
CN – CF	0.50	0.59	-35.18	16.62	386	-2.12	0.2805
CN – BL	0.50	0.74	-87.22	16.62	386	-5.25	0.0000
CN – BD	0.50	0.44	16.00	16.62	386	0.96	0.9293
CN – KS	0.50	0.51	-5.04	16.62	386	-0.30	0.9997
CN – KR	0.50	0.36	43.96	16.62	386	2.65	0.0891
CF – BL	0.59	0.74	-52.04	16.62	386	-3.13	0.0229
CF – BD	0.59	0.44	51.18	16.62	386	3.08	0.0268
CF – KS	0.59	0.51	30.14	16.62	386	1.81	0.4578
CF – KR	0.59	0.36	79.14	16.62	386	4.76	0.0000
BL – BD	0.74	0.44	103.22	16.62	386	6.21	0.0000
BL – KS	0.74	0.51	82.18	16.62	386	4.95	0.0000
BL – KR	0.74	0.36	131.17	16.62	386	7.89	0.0000
BD – KS	0.44	0.51	-21.04	16.62	386	-1.27	0.8034
BD – KR	0.44	0.36	27.96	16.62	386	1.68	0.5443
KS – KR	0.51	0.36	48.99	16.62	386	2.95	0.0394

nificant increase from T1 to T3 ($p = 0.0022$) and from T2 to T3 ($p < 0.001$). These results indicate that recognition accuracy improved over time, with the most substantial improvement observed by the final measurement at T3.

Table 21: Topic-based pairwise comparison with Tukey method family-wise correction for recognition. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.82	0.60	176.22	21.65	731	8.14	0.0000
CN – BL	0.82	0.77	38.25	21.65	731	1.77	0.4880
CN – BD	0.82	0.58	183.39	21.65	731	8.47	0.0000
CN – KS	0.82	0.52	230.74	21.65	731	10.66	0.0000
CN – KR	0.82	0.55	211.67	21.65	731	9.78	0.0000
CF – BL	0.60	0.77	-137.97	21.65	731	-6.37	0.0000
CF – BD	0.60	0.58	7.17	21.65	731	0.33	0.9995
CF – KS	0.60	0.52	54.52	21.65	731	2.52	0.1202
CF – KR	0.60	0.55	35.44	21.65	731	1.64	0.5741
BL – BD	0.77	0.58	145.14	21.65	731	6.70	0.0000
BL – KS	0.77	0.52	192.49	21.65	731	8.89	0.0000
BL – KR	0.77	0.55	173.41	21.65	731	8.01	0.0000
BD – KS	0.58	0.52	47.35	21.65	731	2.19	0.2451
BD – KR	0.58	0.55	28.27	21.65	731	1.31	0.7818
KS – KR	0.52	0.55	-19.07	21.65	731	-0.88	0.9511

Table 22: Time-based pairwise comparison with Tukey method familywise correction for recognition. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
T1 – T2	0.63	0.59	35.70	16.30	731	2.198	0.0722
T1 – T3	0.63	0.70	-55.50	16.30	731	-3.383	0.0022
T2 – T3	0.59	0.70	-90.80	16.30	731	-5.581	0.0000

One-way ANOVA for condition and time: The one-way ANOVA examining recognition (RCG) scores at each time point revealed no significant condition effect at any single time point (Table 23; T1: $F(1, 268) = 0.03$, $p = 0.8552$; T2: $F(1, 268) = 1.44$, $p = 0.231$; T3: $F(1, 268) = 0.04$, $p = 0.8386$). However, the main effect of time was significant for the S group ($F(2, 389) = 11.85$, $p < 0.001$) but only marginal for the C group ($F(2, 372) = 3.01$, $p = 0.0506$), suggesting that recognition performance changed over the course of the experiment, specifically in the S group. Pairwise comparisons with Tukey correction indicated that in the C group, scores decreased slightly from T2 to T3, with the difference reaching marginal significance ($p = 0.0499$; Table 24), whereas the S group showed significant changes between all time points (T1 – T2: $p = 0.039$, T1 – T3: $p = 0.0425$, T2 – T3: $p < 0.001$; Table 25). Overall, these results indicate that the intervention did not produce significant differences at individual time points.

One-way ANOVA for condition and topic: One-way ANOVAs examining the interaction between condition and topic for recognition indicated that, although the overall topic effect was significant for both the C and S groups ($F(5, 369) = 23.42$, $p < 0.001$; $F(5, 386) = 17.89$, $p < 0.001$; Table 26), the simple effects of condition at individual topics were mostly non-significant, with the exception of CF in the SAVE group being marginally significant ($p = 0.0538$). Pairwise comparisons with Tukey's method and family-wise correction

Table 23: One-way ANOVA based on condition and time for recognition due to interaction between them in Table 12 which is not evident or significant at this level of analysis. Condition labels: C = Control, S = SAVE. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of time	T1	0.62	0.64	$F(1, 268) = 0.03$, $p = 0.8552$
	T2	0.61	0.57	$F(1, 268) = 1.44$, $p = 0.2310$
	T3	0.68	0.71	$F(1, 268) = 0.04$, $p = 0.8386$
	Time Effect	$F(2, 372) = 3.01$, $p = 0.0506$	$F(2, 389) = 11.85$, $p = 0.0000$	

Table 24: Control group's time-based pairwise comparison with Tukey correction for recognition. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*-value**
T1 – T2	0.62	0.61	6.64	11.44	372	0.58	0.8309
T1 – T3	0.62	0.68	-20.30	11.44	372	-1.77	0.1799
T2 – T3	0.61	0.68	-26.93	11.44	372	-2.35	0.0499

Table 25: SAVE group's time-based pairwise comparison with Tukey correction for recognition. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*-value**
T1 – T2	0.64	0.57	28.64	11.69	389	2.45	0.0390
T1 – T3	0.64	0.71	-28.25	11.69	389	-2.42	0.0425
T2 – T3	0.57	0.71	-56.89	11.69	389	-4.87	0.0000

revealed that in the C group (Table 27), recognition was significantly higher for CN compared to CF, BD, KS, and KR, and for BL, compared to BD, KS, and KR ($p < 0.05$). In the S group (Table 28), CN showed significantly higher recognition performance compared to CF, BD, KS, and KR, while BL was higher than BD, KS, and KR, and CF was significantly higher than KR ($p < 0.05$).

Table 26: One-way ANOVA based on condition and topic for recognition due to interaction between them in Table 12. Condition labels: C = Control, S = SAVE. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of topic	CN	0.84	0.79	$F(1, 133) = 2.38$, $p = 0.1254$
	CF	0.54	0.65	$F(1, 133) = 3.79$, $p = 0.0538$
	BL	0.78	0.76	$F(1, 133) = 1.03$, $p = 0.3113$
	BD	0.62	0.54	$F(1, 133) = 2.24$, $p = 0.1365$
	KS	0.48	0.56	$F(1, 133) = 1.46$, $p = 0.2296$
	KR	0.56	0.54	$F(1, 133) = 0.41$, $p = 0.5233$
	Topic Effect	$F(5, 369) = 23.42$, $p = 0.0000$	$F(5, 386) = 17.89$, $p = 0.0000$	

Table 27: Control group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table 26 for recognition. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*.value**
CN – CF	0.84	0.54	103.83	14.27	369	7.28	0.0000
CN – BL	0.84	0.78	18.45	14.27	369	1.29	0.7887
CN – BD	0.84	0.62	76.92	14.27	369	5.39	0.0000
CN – KS	0.84	0.48	118.34	14.27	369	8.29	0.0000
CN – KR	0.84	0.56	99.01	14.27	369	6.94	0.0000
CF – BL	0.54	0.78	-85.37	14.27	369	-5.98	0.0000
CF – BD	0.54	0.62	-26.91	14.27	369	-1.89	0.4126
CF – KS	0.54	0.48	14.52	14.27	369	1.02	0.9121
CF – KR	0.54	0.56	-4.82	14.27	369	-0.34	0.9994
BL – BD	0.78	0.62	58.46	14.27	369	4.10	0.0007
BL – KS	0.78	0.48	99.89	14.27	369	7.00	0.0000
BL – KR	0.78	0.56	80.55	14.27	369	5.64	0.0000
BD – KS	0.62	0.48	41.42	14.27	369	2.90	0.0450
BD – KR	0.62	0.56	22.09	14.27	369	1.55	0.6333
KS – KR	0.48	0.56	-19.33	14.27	369	-1.35	0.7539

Table 28: SAVE group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table 26 for recognition. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*.value
CN - CF	0.79	0.65	59.76	15.40	386	3.88	0.0017
CN - BL	0.79	0.76	16.62	15.40	386	1.08	0.8894
CN - BD	0.79	0.54	100.08	15.40	386	6.50	0.0000
CN - KS	0.79	0.56	99.35	15.40	386	6.45	0.0000
CN - KR	0.79	0.54	105.23	15.40	386	6.83	0.0000
CF - BL	0.65	0.76	-43.14	15.40	386	-2.80	0.0594
CF - BD	0.65	0.54	40.32	15.40	386	2.62	0.0953
CF - KS	0.65	0.56	39.59	15.40	386	2.57	0.1071
CF - KR	0.65	0.54	45.47	15.40	386	2.95	0.0389
BL - BD	0.76	0.54	83.46	15.40	386	5.42	0.0000
BL - KS	0.76	0.56	82.72	15.40	386	5.37	0.0000
BL - KR	0.76	0.54	88.61	15.40	386	5.75	0.0000
BD - KS	0.54	0.56	-0.73	15.40	386	-0.05	1.0000
BD - KR	0.54	0.54	5.15	15.40	386	0.33	0.9994
KS - KR	0.56	0.54	5.88	15.40	386	0.38	0.9989

5.3 Perceived User Experience

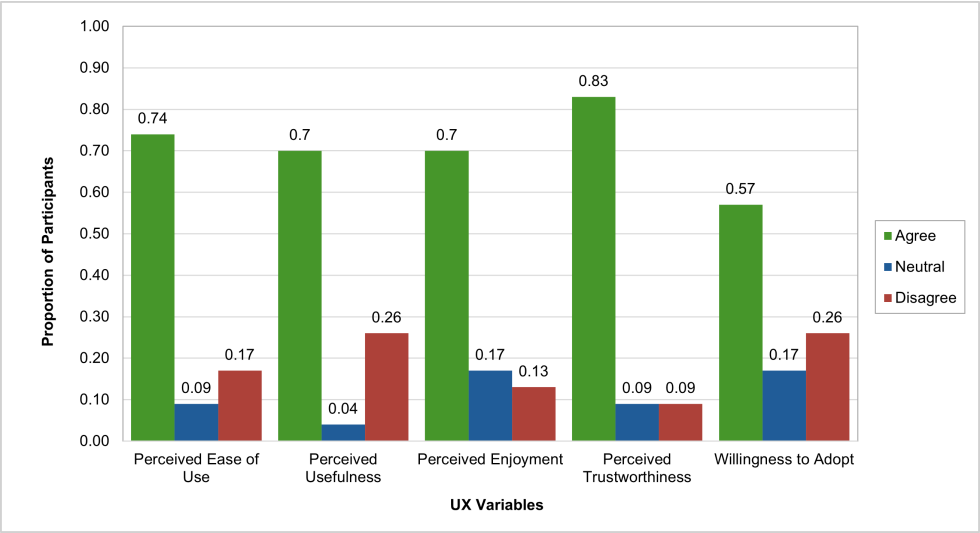
The following subsections focus on the results of the experimental participants' UX analysis.

5.3.1 Perceived UX Ratings

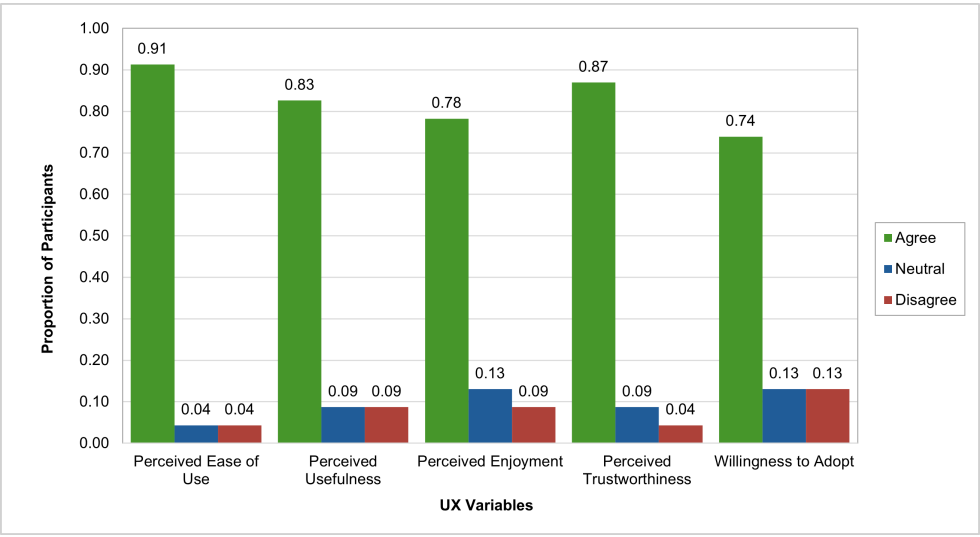
UX ratings across time: Participants provided their UX-based ratings once at T1 and again at T3 for the prompts shown in Table 4. Figure 10 displays the percentage of participants who were in agreement, neutral about, and in disagreement with the perceived UX variables, which are ease of use, usefulness, enjoyment, perceived trustworthiness, and willingness to adopt. Participants' perceptions of the SAVE Tool were generally positive across all dimensions. At Time 1, most participants agreed that the tool was easy to use (74%), useful (70%), enjoyable (70%), and trustworthy (83%), while willingness to adopt was slightly lower at 57%. Neutral and disagreement responses were relatively low across dimensions, implying that overall first impressions were favorable. By T3, agreement increased for all dimensions: perceived ease of use increased to 91%, perceived usefulness to 83%, perceived enjoyment to 78%, trustworthiness remained consistent at 87%, and willingness to adopt to 74%.

5.3.2 ANOVA Results for UX Variables

Overall three-way RMANOVA for UX variables: The three-way RMANOVA revealed significant main effects of condition, time, and UX variable, as well as significant two-way and three-way interactions (Table 29). These results indicate that UX ratings differed by group, changed over time, and varied across UX variables, with the pattern of change depending on the combination of these factors.



(a) Time 1



(b) Time 3

Figure 10: Proportions of participants in the SAVE group who were neutral, agree or disagree to the statement regarding each UX variable at Time 1 and Time 3

Table 29: Overall three-way RMANOVA for UX variables. DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	**Error**	**DF**	**DF.res**	***F* value**	***p*-value**
Condition	PCode	1	44	62.95	0.0000
Time	Within	1	396	63.24	0.0000
UX-variable	Within	4	396	40.74	0.0000
Condition:Time	Within	1	396	63.51	0.0000
Condition:UX-variable	Within	4	396	41.58	0.0000
Time:UX-variable	Within	4	396	12.84	0.0000
Condition:Time:UX-variable	Within	4	396	12.79	0.0000

One-way ANOVA for condition and time: To further examine the condition–time interaction, one-way ANOVAs were conducted at each level of condition and time (Table 30). Across both T1 and T3, the SAVE group showed slightly higher UX ratings than the Control group. Within-group comparisons across time were not statistically significant.

Table 30: One-way ANOVA based on condition and time for UX due to interaction between them in Table 29. Condition labels: C = Control, S = SAVE. Time labels: T1 = Time 1, T3 = Time 3.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of time	T1	4.00	5.04	$F(1, 228) = 57.79$, $p = 0.0000$
	T3	4.00	5.34	$F(1, 228) = 160.73$, $p = 0.0000$
	Time Effect	$F(1, 206) = 1.47$, $p = 0.2264$	$F(1, 206) = 3.08$, $p = 0.0806$	

5.3.3 RMANOVAs and ART-ANOVAs at Time 1 and Time 3

Overall RMANOVA for UX variables at Time 1: At Time 1 (T1), the RMANOVA showed significant main effects of condition and UX variable, as well as a significant condition and UX variable interaction (Table 31). Follow-up ART-ANOVAs indicated that the SAVE group reported higher ratings than the Control group across all UX variables except willingness to adopt, which did not differ significantly (Table 32).

Table 31: Overall RMANOVA for UX variables at Time 1 (T1). DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	**Error**	**DF**	**DF.res**	***F* value**	***p*-value**
Condition	PCode	1	44	33.96	0.0000
UX-variable	Within	4	176	13.66	0.0000
Condition:UX-variable	Within	4	176	12.77	0.0000

Table 32: ART-ANOVA results for perceived UX variables comparing the Control (C) and SAVE (S) groups at Time 1 (T1).

UX Variable	***F* value**	***p*-value**	**Mean (C)**	**Mean (S)**
Perceived Ease of Use	14.21	0.0005	4.00	4.74
Perceived Usefulness	7.36	0.0090	4.00	5.46
Perceived Enjoyment	10.82	0.0020	4.00	5.00
Perceived Trustworthiness	34.69	0.0000	4.00	5.39
Willingness to Adopt	2.49	0.1200	4.00	4.61

Overall RMANOVA for UX variables at Time 3: At Time 3 (T3), the RMANOVA again showed significant effects of condition, UX variable, and their interaction (Table 33). ART-ANOVA results revealed

that the SAVE group consistently reported higher scores than the Control group across all UX variables, including willingness to adopt, with all comparisons reaching statistical significance (Table 34).

Table 33: Overall RMANOVA for UX variables at Time 3 (T3). DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	Error	DF	DF	*F* value	*p*-value
Condition	PCode	1	44	78.48	0.0000
UX-variable	Within	4	176	30.85	0.0000
Condition:UX-variable	Within	4	176	33.17	0.0000

Table 34: ART-ANOVA results for perceived UX variables comparing the Control (C) and SAVE (S) groups at Time 3 (T3).

UX Variable	*F* value	*p*-value	Mean (C)	Mean (S)
Perceived Ease of Use	49.50	0.0000	4.00	5.88
Perceived Usefulness	32.35	0.0000	4.00	5.13
Perceived Enjoyment	20.00	0.0000	4.00	5.33
Perceived Trustworthiness	45.75	0.0000	4.00	5.71
Willingness to Adopt	20.45	0.0000	4.00	4.65

ART-ANOVAs at Time 1 and Time 3: Tables 32 and 34 show that the S group consistently reported positive perceptions of the SAVE Tool. The C group is a simulated control group from a neutral normal distribution, having a mean value of 4. At T1, ART-ANOVA results showed that the S group rated the tool significantly higher on perceived ease of use, usefulness, enjoyment, and trustworthiness, with all effects reaching statistical significance ($p < 0.01$), except for willingness to adopt, which did not differ between groups. At T3, the S group outlined positive results as well with substantially larger F-values and highly significant effects ($p = 0$).

5.3.4 Overall RMANOVA for UX variables for the SAVE group

The RMANOVA for the SAVE group showed a significant main effect of UX variables, indicating that participants rated the five UX variables differently overall (Table 35). Neither the main effect of time nor the interaction between UX variable and time was significant. Tukey-corrected pairwise comparisons revealed that ease of use was rated significantly higher than usefulness and willingness to adopt, and that trustworthiness was rated higher than usefulness (Table 36). Other pairwise differences were not statistically significant.

Table 35: Overall RMANOVA for UX variables for SAVE group. DF = degrees of freedom; DF.res = residual degrees of freedom.

Term	Error	DF	DF.res	*F* value	*p*-value
UX-variable	Within	4	198	8.83	0.0000
Time	Within	1	198	3.41	0.0700
UX-variable:Time	Within	4	198	0.22	0.9300

Table 36: SAVE group's UX variables-based pairwise comparison with Tukey method familywise correction due to the simple effect of *uxvar* in Table 35. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*.value**
Ease of Use – Usefulness	5.67	4.93	41.00	10.90	198	3.77	0.0020
Ease of Use – Enjoyment	5.67	5.17	27.28	10.90	198	2.51	0.0932
Ease of Use – Trustworthiness	5.67	5.55	8.28	10.90	198	0.76	0.9413
Ease of Use – Willingness to Adopt	5.67	4.63	55.61	10.90	198	5.11	< 0.0001
Usefulness – Enjoyment	4.93	5.17	-13.72	10.90	198	-1.26	0.7157
Usefulness – Trustworthiness	4.93	5.55	-32.72	10.90	198	-3.01	0.0246
Usefulness – Willingness to Adopt	4.93	4.63	14.61	10.90	198	1.34	0.6651
Enjoyment – Trustworthiness	5.17	5.55	-19.00	10.90	198	-1.75	0.4084
Enjoyment – Willingness to Adopt	5.17	4.63	28.33	10.90	198	2.60	0.0737
Trustworthiness – Willingness to Adopt	5.55	4.63	47.33	10.90	198	4.35	0.0002

6 Discussion

6.1 Interpretation of Results

The following subsubsections interpret the results of the experiment. First, the results of the pre-design survey are discussed. Then, each subsubsection focuses on a specific hypothesis, examining the performance differences between the SAVE and Control groups across the measured topics. Observed trends, statistical significance, and potential implications for learning and mnemonic strategies are discussed.

6.1.1 Pre-Design Survey

The pre-design survey was used to identify participants' preferences for both mnemonic characteristics and mnemonics-based tool features, which were then incorporated into the design of the SAVE Tool (Table 8). Many responses emphasized the need for recommendations, referring to guidance or suggestions that help learners generate effective mnemonics as well as reduce cognitive load during creation [40] [79]. Participants also frequently requested visuals, indicating a preference for imagery and visual structure to improve dual coding and memorability [80]. Requests for customization and personalization reflected a desire to adapt mnemonic creation to individual preferences, prior knowledge, or learner styles, which has been shown to promote engagement and deeper encoding [81] [82]. Similarly, calls for flexibility and multiple mnemonics suggest that learners value the ability to create, revise, and compare different memory cues to support active learning. While fewer responses focused on mnemonic characteristics themselves, such as being meaningful, topic-relevant, or humorous, these features align with established memory principles, including elaborative encoding, semantic association, and distinctiveness, all of which contribute to stronger recall [22] [83] [84]. Collectively, these themes were integrated into the design and development of the SAVE Tool features, *My Toolbox* and *Workbench*, grounding the system in empirically supported memory strategies and user expectations.

6.1.2 H1: The SAVE Tool will lead to higher students' performance across all six topics than the control condition

The hypothesis predicted that participants using the SAVE Tool (SAVE or S group) would outperform those in the control condition (Control or C group) across all six topics: Biological Organization Levels (BL), Biological Organization Disciplines (BD), Cranial Nerves (CN), Cranial Nerve Functions (CF), Krebs Cycle Substrates (KS), and Krebs Cycle Reactions (KR). The overall four-way RMANOVA revealed no main effect of condition (Table 10), but a significant condition $\times$ topic interaction indicates that the influence of the SAVE Tool varied meaningfully by topic. This pattern suggests that the benefits of SAVE were not uniform across the curriculum, but were instead shaped by the nature and cognitive demands of each topic [85].

Across topics, Biological Organization Levels (BL) consistently produced the highest scores in both groups, indicating that this domain may be conceptually simpler or more familiar to students (C: 0.75, S: 0.75) (Table E.2.4). This is evident by the comparatively high familiarity scores of BL (C: 3.53, S:

3.80; Figure 6), further discussed in Section 6.1.8. The lack of condition difference for BL suggests a potential ceiling effect, wherein students performed well regardless of study method. Similarly, no condition difference was observed for Cranial Nerves (CN) ($F(1, 268) = 0.29$, $p = 0.5880$) or Krebs Cycle Reactions (KR) ($F(1, 268) = 0.03$, $p = 0.8564$) (Table E.2.4), implying that these topics may rely on recognizable patterns, prior course exposure, or structured mnemonics that helped both groups equally.

In contrast, three topics demonstrated significant effects for the S group: Cranial Nerve Functions (CF) ($F(1, 268) = 8.22$, $p = 0.0045$), Krebs Cycle Substrates (KS) ($F(1, 268) = 7.59$, $p = 0.0063$), and marginally Biological Organization Disciplines (BD) ($F(1, 268) = 3.74$, $p = 0.0541$) (Table E.2.4). For CF and KS, the S group scored significantly higher than the C group, aligning with research showing that spaced retrieval is especially helpful detailed, interconnected information [86]. Both CF and KS involve memorizing paired relationships (nerve-function or substrate-reaction), which are known to benefit from repeated, cue-dependent engagement, an approach aligned with active learning principles, where learners interact with and process the material rather than passively reviewing it [85]. The marginally lower BD performance in the S group may reflect topic characteristics rather than tool limitations. BD involves semantics and classification rather than sequential associations, which may receive less direct benefit from mnemonic-featured retrieval practice.

Topic-level pairwise comparisons show that BL was the strongest topic in both groups, significantly outperforming BD, KS, and KR in the control condition (e.g., BL – KS estimate = 214.28, $p < 0.001$), consistent with prior work showing that biochemical pathways require heavy integrative reasoning [87]. However, the S group exhibited smaller performance gaps between topics, indicating more balanced learning. For example, BD and KS differed significantly in the C group (estimate = 91.24, $p < 0.001$), but did not differ in the S group (estimate = -25.55, $p = 0.89$), and KS, one of the lowest performing-topics, showed a notable improvement relative to the control condition. This pattern suggests that the SAVE Tool may help elevate performance on inherently challenging or less intuitive topics, aligning with evidence that active learning approaches enhance comprehension and retention of difficult material [18].

The significant condition $\times$ time interaction in the overall model also supports the interpretation that SAVE users improved more across time points than the C group. This cumulative benefit aligns with theories of spaced learning [88], as SAVE provided repeated exposure and active engagement across the study period rather than one-time review. Although these improvements did not translate into a global condition effect across all topics, the topic-dependent advantages point to content-specific benefits of the SAVE Tool.

Taken together, the results partially support H1. The SAVE Tool meaningfully improved performance for three of the six topics (CF, KS, and BD marginally), particularly those requiring associative recall, sequential understanding, or multi-step processing. While some high-performing or structurally simpler topics (BL, CN, KR) showed no condition differences, the observed interaction effects highlight the SAVE Tool's potential as a targeted support tool for challenging or cognitively demanding domains. These findings reinforce broader learning science literature showing that active learning strategies, which involve engaging learners directly with complex and unfamiliar material, are most effective when content requires integration of multiple elements [18], suggesting that the SAVE Tool may be particularly well-suited for such instructional contexts.

6.1.3 H2a: The SAVE group will have higher recall scores than the Control group

The results provide partial support for the hypothesis that the S group would achieve higher recall (RCL) scores than the C group. The overall one-way ANOVA based on condition and time (Table 15) showed that although the main effect of condition was not statistically significant at Time 1 (T1; $p = 0.0784$) and Time 2 (T2; $p = 0.5136$), a significant advantage emerged at Time 3 (T3; $F(1, 268) = 4.11$, $p = 0.0437$). These findings indicate that the benefit of the SAVE Tool on recall become more evident with repeated exposure, consistent with theories of spaced practice and cumulative learning [89] [90].

Time-based pairwise comparisons (Tables 16 and 17) showed that both groups improved their recall scores across time points, but the magnitude of improvement was greater in the SAVE group. For example, the score increase from T1 to T3 was 0.23 in the Control group versus 0.23 in the SAVE group, with the SAVE group displaying stronger statistical evidence of improvement ($t = -7.53$, $p < 0.001$). These results suggest that the structured mnemonic support and active engagement provided by the SAVE Tool facilitated retention over repeated learning sessions.

Topic-level analyses (Table 18) further highlight that the S group consistently outperformed the C group across most topics. Statistically significant improvements in recall were observed for CN ($p = 0.0150$) and KS ($p = 0.0151$), while other topics showed positive trends in favor of the S group, even when not reaching statistical significance (e.g., CF, KR). Tukey-corrected pairwise comparisons (Tables 19 and 20) reveal that these topic-level differences were robust and aligned with the observed overall trends.

Taken together, these findings indicate that while the SAVE Tool did not uniformly produce statistically significant gains in recall across all topics and time points, it enhanced learning over time and led to higher recall scores on multiple topics, supporting the hypothesis in a nuanced manner. The increasing performance trend over repeated sessions suggests that mnemonic-based and structured study strategies may require repeated engagement to realize their full benefit [81] [91].

Overall, the hypothesis is partially supported, reflecting a gradual and cumulative benefit of the SAVE Tool on recall performance, especially evident at later time points and across multiple topics.

6.1.4 H2b: The SAVE group will have higher recognition scores than the Control group

The results provide partial support for the hypothesis that the S group would achieve higher recognition (RCG) scores than the C group. The overall one-way ANOVA based on condition and time (Table 23) showed that there were no statistically significant differences between groups at T1 ($p = 0.8552$), T2 ($p = 0.2310$), or T3 ($p = 0.8386$). These results suggest that the main effect of the SAVE Tool on recognition was not uniform across time.

Time-based pairwise comparisons (Tables 24 and 25) showed that both groups generally improved over time, with the S group showing larger magnitude gains between time points. For example, in the S group, the recognition scores increased from T2 to T3 by 0.14 ($t = -4.87$, $p < 0.001$), whereas the C group showed smaller gains (T2 to T3: 0.07, $t = -2.35$, $p = 0.0499$). These patterns suggest that the SAVE Tool may facilitate gradual improvement in recognition when participants are repeatedly exposed to the material, even if the overall effect does not reach significance at each time point.

Topic-level analyses (Table 26) further show that recognition performance was largely comparable between groups, with some topics showings small numerical advantages for the S group (e.g., CF: S = 0.65 vs. C = 0.54, $p = 0.0538$) while others favored the C group or showed minimal differences. Tukey-corrected pairwise comparisons (Tables 27 and 28) demonstrate that these differences were mostly nonsignificant, reflecting the relatively high baseline recognition performance in both groups and suggesting a potential ceiling effect [92].

Altogether, these findings indicate that while the SAVE Tool did not produce consistently significant improvements in recognition scores across topics and time points, it was associated with slightly higher gains over repeated exposure. This pattern implies that the tool may provide some advantage in consolidating recognition performance, particularly in the later stages of learning sessions.

Overall, the hypothesis is partially supported, as the S group showed directional improvements in recognition, particularly over time, but the effect was less pronounced than for recall and did not reach consistent statistical significance across all measures.

6.1.5 H3(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 1 compared to the Control group

The hypothesis predicted that participants in the S group would demonstrate higher recall scores at Time 1 compared to the C group. The data show that, at T1, the S group had a mean recall score of 0.52, compared to 0.45 in the C group (Table 15). Although this difference was no statistically significant ($F(1, 268) = 3.12$, $p = 0.0784$), there is a trend favoring the S group. Time-based pairwise comparisons reveal that both groups exhibited significant improvements over time (Tables 16 and 17), with the S group showing larger gains between T1 and following time points.

These results indicate that the SAVE Tool may support initial recall performance, but the lack of a statistically significant difference at Time 1 suggests that the effect might be modest at the earliest stage of learning. Overall, while the hypothesis is partially supported, the findings suggest that the advantage of the S group may become apparent over time rather than immediately.

For recognition, the S group had slightly higher scores at Time 1 (0.64) compared to the C group (0.62), but the difference was not significant ($F(1,268) = 0.03$, $p = 0.8552$; Table 23). This pattern is indicative of a potential ceiling effect [92], as both groups achieved relatively high recognition scores even at the first measurement. High initial performance may have limited the ability to detect substantial differences between conditions.

Despite the lack of statistical significance at T1, the data show that the S group achieved marginally higher recognition scores immediately after the learning intervention. This suggests that the tool may provide an early benefit in supporting recognition memory, even if the effect is subtle. Emphasizing T1 performance highlights the immediate impact of the intervention, which is particularly relevant for applications where rapid acquisition of knowledge is important.

Overall, the findings provide partial support for the hypothesis at Time 1. While neither recall nor recognition differences were statistically significant at the first measurement, the S group consistently showed higher initial scores, suggesting a potential early advantage that may become more pronounced under differ-

ent task conditions or with larger samples.

6.1.6 H4(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 2 compared to the Control group

At Time 2, the S group have a mean recall score of 0.30, slightly higher than the C group at 0.29 (Table 15). This difference was not statistically significant ($F(1,268) = 0.43$, $p = 0.5136$), indicating comparable recall performance between the groups at this point. Both groups experienced a substantial decline from their Time 1 scores (S: 0.52 to 0.30; C: 0.45 to 0.29; Tables 17 and 16), which corresponds to the period during which participants did not engage with the content. This gap in rehearsal likely contributed to the decrease in recall performance, highlighting the well-documented decay effect of memory when information is not reinforced [68]. Despite the overall decline, the S group maintained a slight advantage over the C group, suggesting that the initial engagement with the SAVE Tool may provide some retention benefit even without active rehearsal.

For recognition at Time 2, the S group scored 0.57, slightly lower than the C group's 0.61 (Table 23), though this difference was not statistically significant ($F(1,268) = 1.44$, $p = 0.231$). Both groups showed a modest decline from Time 1 (S: 0.64 to 0.57; C: 0.62 to 0.61; Tables 25 and 24), consistent with the expected memory decay following a period without exposure or rehearsal. The gap between T1 and T2 scores emphasizes the importance of continuous engagement for maintaining recognition performance. While the S group did not outperform the C group at this time point, the results suggest that the tool may have helped sustain recognition performance despite the lack of rehearsal.

Overall, this hypothesis was not supported at Time 2, as the SAVE group did not show statistically higher recall or recognition scores than the Control group. Although the SAVE group demonstrated a slight advantage in recall and comparable recognition performance, these differences were not significant. The marked decline from Time 1 to Time 2 in both groups highlights the impact of memory decay in the absence of rehearsal. Nonetheless, the SAVE group's marginal retention trends suggest a limited, non-significant benefit of the tool at this time point, indicating that sustained or repeated engagement may be necessary for clearer effects to emerge.

6.1.7 H5(a, b): The SAVE group will have higher scores for both recall and recognition tasks at Time 3 compared to the Control group

At Time 3, the S group demonstrated a substantial improvement in recall, achieving a mean score of 0.75 compared to the C group's 0.64 (Table 15). This difference was statistically significant ($F(1,268) = 4.11$, $p = 0.0437$), supporting the hypothesis that participants using the SAVE Tool performed better than those in the C group. The marked increase from Time 2 (S: 0.30 to 0.75; C: 0.29 to 0.64; Tables 17 and 16) aligns with the spacing effect: distributing learning and review sessions over time tends to strengthen retention more than massed or single-session learning [88]. Research shows that spaced learning consistently produces better long-term memory than immediate successive studying [88] [93]. This suggests that the SAVE Tool may enhance recall by leveraging spaced reinforcements rather than relying on a single exposure.

For recognition at Time 3, the S group scored 0.71 versus 0.68 for the C group, though this difference was not statistically significant ($F(1,268) = 0.04$, $p = 0.8386$; Table 23). Both groups improved from T2

(S: 0.57 to 0.71; C: 0.61 to 0.68), suggesting that engagement with the material after a delay helped restore recognition performance. While the advantage for SAVE is modest, the overall increase in both groups is consistent with spaced exposure benefiting recognition memory as well, as documented in spaced-learning literature [94]. Although the recognition scores did not differ significantly, the revision session likely reinforced participants' recall of the material, which may have contributed to freeing cognitive resources and supporting their recognition performance.

Overall, this hypothesis was partially supported at Time 3. The hypothesis was validated for recall, as the SAVE group achieved significantly higher recall scores than the Control group, indicating a clear benefit of the SAVE Tool for long-term recall. In contrast, the hypothesis was not supported for recognition, as both groups showed similar improvements and the difference between them was not statistically significant. These findings suggest that while the SAVE Tool is effective in enhancing recall after a delayed interval, likely through spaced reinforcement, its advantage for recognition performance is more limited. Collectively, the results indicate that the tool's strongest impact at Time 3 lies in supporting deeper, recall-based learning.

6.1.8 H6(a – c): The SAVE group will have higher overall scores and higher recall and recognition scores in difficult topics compared to the Control group

The analysis of overall performance across topics indicate that the S group consistently outperformed the C group on more difficult topics, supporting the hypothesis that the SAVE Tool supports learning in areas of lower familiarity. One-way ANOVA results (Table E.2.4) showed that for challenging topics such as CF and KS, the condition effect was significant (CF: $F(1, 268) = 8.22$, $p = 0.0045$; KS: $F(1, 268) = 7.59$, $p = 0.0063$), whereas for easier topics like BL, there was no significant difference between groups, suggesting that baseline familiarity constrains observable gains. Difficult topics are established in Figure 6. The topics, in the order of least to most familiar, KS (C: 2.05, S: 1.90), KR (C: 2.26, S: 1.85), CN (C: 2.16, S: 2.20), and CF (C: 2.21, S: 2.20), are considered challenging based on the low familiarity scores. Meanwhile, BD (C: 3.42, S: 3.20) and BL (C: 3.53, S: 3.80), have higher familiarity scores, implying that they are comparatively easier topics.

Topic-based pairwise comparisons (Tables E.2.5 and E.2.6) further highlighted that the S group achieved higher scores on difficult topics (e.g., CN, CF, KS, and KR), while performance on simpler topics was similar between groups. This pattern indicates that the intervention specifically benefits learning when content is inherently more difficult or unfamiliar.

These findings can be interpreted in light of the spacing effect, which suggests that distributed exposure and practice improves retention, especially for challenging material [88]. For easier topics, performance may have approached a ceiling, limiting observable differences despite the intervention. Overall, the results demonstrate that the SAVE Tool is effective in enhancing comprehension and retention for topics that present greater difficulty to learners, highlighting its potential as a target learning strategy for complex content.

The analysis of recall scores across topics indicates that the S group achieved higher performance on more difficult topics compared to the C group, supporting the hypothesis that the SAVE Tool enhances learning in areas of lower familiarity. One-way ANOVA results (Table 18) showed significant condition effects for CN ($F(1, 133) = 6.08$, $p = 0.0150$) and KS ($F(1, 133) = 6.07$, $p = 0.0151$), which are among

the least familiar topics, while easier topics such as BL showed no significant differences between groups. These results suggest that the SAVE Tool particularly benefits recall for content that learners initially find challenging.

Topic-based pairwise comparisons (Tables 19 and 20) reinforce this pattern. The S group demonstrated notably higher recall scores for difficult topics such as KR, KS, and CN, while scores for more familiar topics remained comparable between groups. For example, the difference in recall between the S and C groups was largest for KR and KS, highlighting the intervention's efficacy for lower familiarity content.

These findings align with the spacing effect, which posts that distributed exposure improves retention, particularly complex or challenging material [88]. The results suggest that the SAVE Tool supports learners in consolidating difficult information, thereby reducing the typical performance gap observed in less familiar topics. Overall, the data demonstrate that the SAVE Tool effectively enhances recall for challenging material, emphasizing its potential as a strategy for targeted learning in difficult domains.

The analysis of recognition scores indicates that the S group generally outperformed the C group on more difficult topics, providing partial support for the hypothesis that the SAVE Tool enhances recognition of challenging content. While one-way ANOVA results (Table 26) did not reveal statistically significant differences for individual difficult topics such as CN ($p = 0.1254$), KS ($p = 0.2296$), and KR ($p = 0.5233$), the pattern of mean scores consistently favored the S group. For example, the S group's recognition scores were higher than the C group for CN (0.79 vs. 0.84), KS (0.56 vs. 0.48), and KR (0.54 vs. 0.56), suggesting a trend toward improved recognition of less familiar content.

Topic-based pairwise comparisons (Tables 27 and 28) further support this trend. Within the S group, significant differences were observed between the most difficult topics and easier ones, with higher recognition scores for challenging content such as CN, KS, and KR relative to other difficult topics (e.g., CF and BD). These results indicate that the SAVE Tool may help learners discriminate and retain key information in less familiar topics, even if the differences do not reach significance in simple condition-level comparisons.

Overall, this hypothesis was partially supported. The hypothesis was strongly validated for overall performance and recall in difficult topics, where the SAVE group consistently outperformed the Control group, particularly for content with lower prior familiarity. These results indicate that the SAVE Tool is especially effective in supporting deeper learning and recall when material is complex or unfamiliar. In contrast, support for recognition in difficult topics was more limited: although mean recognition scores generally favored the SAVE group, these differences did not reach statistical significance. This pattern suggests that the SAVE Tool may help learners manage cognitive load when processing less familiar material by providing structured cues that reduce extraneous processing and allow greater focus on essential content [40]. Although the effect was more pronounced for recall than recognition, the findings highlight the SAVE Tool's potential as an effective intervention for improving understanding and retention in difficult topics rather than for content with high baseline familiarity.

6.1.9 H7: The recognition task for both conditions will have a higher score than the recall task overall

The results for H7 were strongly supported. Across both conditions, participants performed significantly better on the recognition task than on the recall task. This pattern was evident in the four-way RMANOVA,

which showed a robust main effect of task ($F(1, 1505) = 161.66$, $p < 0.001$), indicating that recognition scores were consistently higher than recall scores at the overall level. This effect remained stable even when recall (RCL) and recognition (RCG) were analyzed separately in the three-way RMANOVAs, where task-based differences were again highly significant for both conditions (Tables 11 and 12). Follow-up analyses showed that while condition did not meaningfully influence recognition performance, recall scores differed slightly by condition, yet the task effect remained substantially larger (Table E.2.3). Together, these findings demonstrate a clear and reliable advantage for recognition over recall across the experiment.

This pattern aligns with a well-established body of memory research showing that recognition is cognitively easier than recall [28]. Recognition tasks provide external cues that help guide retrieval of information, reducing the need for self-initiated search processes. Extensive empirical evidence shows that recognition generally produces higher accuracy than recall because it requires less effortful retrieval and depends more heavily on familiarity-based processing [29] [30]. Behavioral studies comparing the same materials across tasks typically find that recall performance declines more sharply with task demands or cognitive load, whereas recognition remains comparatively robust [31]. Neuroimaging evidence similarly shows that recall utilizes more widespread regions associated with strategic retrieval, whereas recognition requires fewer cognitive resources, offering a mechanistic explanation for why recognition tends to outperform recall [32].

The present findings fit squarely within this literature. Participants were required to retrieve information at multiple time points, and recall performance was consistently lower, especially as delays increased. This pattern is consistent with the greater susceptibility of recall to forgetting. Recognition, on the other hand, remained comparatively resilient over time, reflecting the support offered by item-level cues. The significant main effect of time in both recall and recognition further shows that memory decayed across delays. However, the decline in recall was much steeper, reinforcing that recall involves more effortful and reconstructive retrieval processes.

Overall, hypothesis H7 is strongly validated by the results. Recognition was reliably and substantially easier for participants than recall across topics, conditions, and time points. These findings are consistent with decades of cognitive psychology research demonstrating that recognition benefits from externally provided cues and reduced retrieval demands, whereas recall requires active generation of information from memory. Accordingly, the task-based performance differences observed in this study reflect fundamental distinctions in human memory processes rather than differences attributable to experimental conditions.

6.1.10 H8: The SAVE Tool will be perceived as easy to use, useful, enjoyable, trustworthy, and will foster users' willingness to adopt it

Participants reported positive perceptions of the SAVE Tool over time, demonstrating that the design effectively supported ease of use, usefulness, enjoyment, and trust while willingness to adopt seems to have potential. The high agreement rates at T1 imply that users formed favorable impressions of the tool, which is an important early predictor of engagement and sustained interaction in learning interfaces [33] [34]. The improvement in perceived ease of use, usefulness, enjoyment, trust, and adoption at T3 align with the Technology Acceptance Model (TAM), which states that usability and received utility become stronger as users gain experience and confidence with a system [35]. The consistently high trustworthiness scores across both

time points suggest that the tool conveyed reliability and stability, qualities shown in prior work to increase users' willingness to use educational technologies [36].

The ART-ANOVA results support the descriptive trends of high ratings for the perceived UX factors. The S group rated the SAVE Tool significantly higher than the simulated control group on key UX dimensions at both T1 and T3, with especially larger effects at T3. This pattern indicates that repeated and extended hands-on interaction reinforced positive perceptions, consistent with research showing that usability benefits and perceived value often strengthen with continued exposure [95] [96]. The initially non-significant difference in willingness to adopt at T1, and then emerging improvement by T3, fits with literature demonstrating that intention to adopt typically develops more gradually and requires accumulated positive experience rather than immediate impressions [97]. Together, these findings suggest that the SAVE Tool offers a strong and improving user experience that supports active engagement and long-term learning use.

Overall, H8 was largely supported, with strong evidence validating users' positive perceptions of the SAVE Tool across key UX dimensions. Participants consistently perceived the SAVE Tool as easy to use, useful, enjoyable, and trustworthy, with these perceptions strengthening over time, particularly after extended interaction. While willingness to adopt did not differ significantly at the initial time point, its improvement by Time 3 suggests a developing intention to use the tool that emerges with sustained experience rather than immediate exposure. Taken together, these results indicate that H8 is fully supported for ease of use, usefulness, enjoyment, and trust, and partially supported for willingness to adopt, highlighting the SAVE Tool's capacity to foster positive and durable user acceptance over time.

6.1.11 H9: Users will be willing to adopt the SAVE Tool given its perceived ease of use, perceived usefulness, perceived enjoyment, and perceived trustworthiness

The hypothesis proposed that users will be willing to adopt the SAVE Tool given its perceived ease of use, perceived usefulness, perceived enjoyment, and perceived trustworthiness. The results provide full support for this hypothesis, with a clear pattern over time that aligns with technology acceptance theory.

At T1, participants in the S group rated the tool significantly higher than the C group on perceived ease of use, usefulness, enjoyment, and trustworthiness. These early impressions demonstrate that the tool was immediately perceived as intuitive, beneficial, enjoyable, and credible. However, willingness to adopt did not yet differ significantly between groups. This initial pattern is not unexpected in line with the Technology Acceptance Model (TAM), which suggest that behavioral intention to adopt often lags behind early perceptions, particularly when users have limited hands-on experience [33] [35].

By T3, after participants had actively engaged with the SAVE Tool as part of the instructional sequence, all UX dimensions, including willingness to adopt, were significantly higher for the S group. The significant increase in adoption intention over time indicates that participants' positive perceptions translated into a genuine willingness to integrate the tool into their learning processes. This shift is further supported by the within-group RMANOVA showing no significant interaction between UX variables and time, suggesting that the S group's consistently positive ratings across ease of use, usefulness, enjoyment, and trustworthiness formed a stable foundation upon which adoption intentions strengthened.

The temporal progression, from strong initial perceptions to later increases in adoption intention, is

theoretically meaningful. TAM posits that perceived ease of use and usefulness exert their influence on behavioral intention more strongly as users gain experience with the system [33] [35]. Similarly, research in educational technology emphasizes the role of experiential familiarity in shaping enjoyment and trust, which in turn strengthen learners' willingness to adopt new tools [37]. The results of the present study follow the trajectory of positive perceptions being established early, and willingness to adopt emerged as significant once participants had sufficient exposure to the tool.

Taken together, the combined T1 and T3 findings provide complete support for the hypothesis. Although willingness to adopt was not initially higher for the S group, it became significantly higher by T3, which is exactly when TAM and related literature predict adoption intentions should manifest. This pattern indicates that the SAVE Tool not only generated favorable perceptions but also successfully motivated users toward adoption after meaningful use, confirming the central premise of the hypothesis.

6.1.12 Integrative Interpretation

In summary, the results indicate that the SAVE Tool enhances active learning, improves comprehension, and strengthens both recall and recognition, especially for complex topics and after spaced review. While some differences are marginally significant, the consistent trends across tasks, topics, and time points, suggest that the tool provides meaningful advantages over passive study methods. These benefits are likely supported by the participants' positive perceptions of the tool's ease of use, usefulness, enjoyment, trust, and willingness to adopt, which likely contributed to their sustained engagement and effective learning [33] [34] [36]. Altogether, these findings align with literature emphasizing the importance of engagement, elaboration, and structured learning in improving retention and understanding [85] [98] [19], highlighting the need to coordinate enhanced learning outcomes with strong user experience.

6.2 Limitations

Several limitations of this study should be acknowledged. First, the sample was limited to university students, and the number of participants was relatively small. This may restrict the generalizability of the findings to other populations, like learners in different educational contexts. Because the sample was restricted to York University students, cultural and contextual factors may influence the findings. The tool's effectiveness may also vary for different student groups, such as mature or part-time students, and could differ further in other regions, particularly in non-English educational settings. The majority of participants were of South Asian ethnicity (C: 73%, S: 65%; Figure D.1.5), which may limit the broader applicability of the findings. Future research should evaluate the effectiveness of the SAVE Tool across more diverse ethnic groups.

Second, regarding the scope of the tool, participants primarily used researcher-created mnemonics rather than generating their own. While this ensured consistency across the study and helped control the amount of time for the experiment, it may not fully reflect how students would interact with the tool in authentic, realistic learning situations.

Third, the evaluation design focused on immediate or short-term learning outcomes. Longer-term retention and the transfer of knowledge to applied contexts were not extensively assessed, limiting conclusions about the durability of learning gains. Additionally, user engagement and experience may have been

influenced by individual differences such as prior experience with mnemonics, motivation to participate, familiarity with the biology topics, or technical literacy, which were not controlled in the study.

Another limitation is an error that occurred during data processing. Within the SAVE group, Participant S21 was intended for exclusion due to signs of disengagement (as indicated by our outlier analysis), reflected in consistently low scores across all three time points (T1: 0.11, T2: 0.03, and T3: 0.28; Table D.2.1). However, Participant S22, who demonstrated strong performance and did not meet the exclusion criteria (T1: 0.38, T2: 0.20, and T3: 0.67) was mistakenly removed instead. This misclassification likely introduced unnecessary noise into the dataset and may have modestly reduced the observed effectiveness of the SAVE condition, as the excluded participant would have otherwise contributed positively to the group's overall performance.

Examining the data showed another potential limitation related to participant motivation and engagement as the term progresses. A study found that undergraduate participants who sign up for studies early in the semester exhibit higher sustained attention and intrinsic motivation than those who sign up later [99]. By contrast, participants recruited later tend to show marked declines in motivation and performance. Because our data collection extended from the start of the term through the Fall semester, some participants may have experienced lower motivation or exhibited reduced effort as the term progressed. This could have negatively influenced their performance, meaning the true effectiveness of the SAVE Tool may have been underestimated.

Finally, the scalability of the SAVE Tool remains untested in larger courses or across multiple courses running simultaneously. Although the tool performed well in the current study, its effectiveness, usability, and administrative feasibility may change when used with bigger groups, varied disciplines or different instructional formats.

6.3 Future Work

While this thesis has demonstrated the potential of the SAVE Tool in supporting mnemonics-based learning and improving long-term retention, there are several paths for future research. First, future studies could benefit from exploring the impact of self-generated mnemonics rather than using pre-constructed mnemonics. Prior research suggests that self-generated mnemonics lead to deeper encoding and stronger recall compared to externally provided mnemonics, particularly in complex subject domains such as chemistry and biology [22] [79].

Second, expanding the participant pool to larger and more diverse samples would improve the generalizability of the findings. Recent studies on interactive mnemonic tools often rely on small or homogeneous samples, which limits their external validity and makes it difficult to determine whether the observed effects would hold across different student populations, educational settings, or cultural contexts. Increasing both the size and diversity of participants would allow researchers to explore potential differences in tool effectiveness based on factors such as prior knowledge, learning styles, or demographic characteristics. Moreover, larger samples would provide greater statistical power, enabling more robust detection of nuanced effects and interactions that may be undiscovered in smaller samples. Reviews of mnemonic-based serious games and educational tools recommend more large-scale evaluations to better understand real-world impact and ensure

that findings can be meaningfully translated into educational practice [100] [1].

Third, enhancing the user experience and personalization of the SAVE Tool by including adaptive mnemonic suggestions, customizable visualization styles, or individualized review schedules represents a promising direction. Research has shown that personalized mnemonic interventions, such as music-based or adaptive mnemonics, can improve engagement, motivation, and retention, suggesting that tailoring the tool to individual learners' preferences may increase its effectiveness [82].

Finally, future work could expand the scope of evaluation to include usability, engagement, and long-term adoption metrics, rather than solely focusing on remembering and certain UX factors. Understanding how students interact with the tool over time and the factors influencing sustained usage will provide insight into its practical utility in higher education settings [101].

Collectively, these directions highlight the potential to refine, expand, and better evaluate the SAVE Tool to maximize its educational impact in memory-intensive courses.

7 Conclusion

This thesis explored the effectiveness of an interactive mnemonics-based learning system called the SAVE Tool, designed to promote active engagement with educational material. Building on research on mnemonic-supported learning and structured study interfaces by Oyibo [38], the study examined whether the SAVE Tool improved learners' recall (RCL), recognition (RCG), and perceived user experience (UX) compared to a control condition that did not use the tool. Across the study, learners using the SAVE Tool demonstrated significantly stronger recall performance, while recognition performance was high but not significantly different, highlighting the tool's potential to reinforce memory retention through spaced review and mnemonic support. These outcomes align with prior work that discusses using active learning strategies to deepen understanding even if immediate performance gains are marginally significant [19] [69].

Furthermore, the SAVE group showed favorable results from a UX perspective. At both Time 1 and Time 3, participants rated the SAVE Tool significantly higher for ease of use, usefulness, enjoyment, and trustworthiness. These differences are especially highlighted at Time 3, suggesting that the tool becomes more valuable as it is repeatedly used. While willingness to adopt was not statistically significant at Time 1, a significant effect emerged at Time 3, displaying a later increase in participants' willingness to adopt the SAVE Tool.

Collectively, these findings contribute to the broader understanding of structured active-learning, interactive mnemonic-based tools. The SAVE Tool produced significant results for recall as well as high recognition performance, which was not significantly different, within the timeframe of the experiment. The strong UX perception of the SAVE Tool and the stability of learning outcomes imply a potential for educational use. Participants not only found the tool intuitive and helpful, but also viewed it as trustworthy and enjoyable, which are qualities that can potentially result in the long-term adoption of learning technologies.

Future work should extend exposure duration, incorporate delayed post-tests to assess retention in longer-term contexts, and explore how different types of mnemonics, such as self-created and mastered, free up cognitive resources and/or influence comprehension in the long run. Additionally, investigating personalization or learner-driven control within mnemonic creation or active learning may support durable cognitive outcomes.

Overall, this thesis demonstrates that the SAVE Tool is a promising interactive resource for active learning in memory-intensive courses. Its positive user experience, increasing perceived usefulness, and steady learning outcomes provide a strong foundation for further refinement and integration into educational settings, where mnemonics-based tools can be used as an effective, well-organized support for students' engagement and long-term learning.

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Appendices

A Appendix A: Pre-Experiment Study Instruments

A.1 Consent Form

Researchers:

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Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of mnemonics used in tools for learning course material. The research explores whether using a tool will help with learning mnemonics.

What You Will Be Asked to Do in the Research: You are required to provide your answers to the questions in the questionnaire. You will also be asked to provide key demographic information such as age, gender, education, and your grade performance as a student in the questionnaire.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You: The benefit of the research is that you will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $10.

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the $10 for agreeing to be in the project, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a

password-protected Google Drive. The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Please note that the survey is being conducted with the help of Google Forms, a company not affiliated with York University and with its own privacy and security policies that you can find at https://transparency.google/our-policies/product-terms/google-forms/. There is always a risk during web-based transmission that data can be intercepted by a third party (e.g., government agencies, hackers) and thus confidentiality and privacy cannot be guaranteed.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo@yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My choice below indicates my consent.

    ○ Yes

    ○ No

2. I understand that my de-identified data will be placed into an open research data repository.

    ○ Yes

    ○ No

3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any responses—whether brief or detailed—provided in the open-ended sections of the survey.

   - ○ Yes
   - ○ No

A.2 Part 1

Survey

Instructions: Please note that there are 3 parts for this survey. You must fill out all 3 parts to complete the survey and be able to provide payment details (at the end of the 3rd part). The link to the next part of the survey will be displayed in the confirmation message that appears after you click the submit button.

Mnemonics work as retrieval cues that trigger the recall of information from long-term memory. Mnemonics can be classified into two types: acrostics and acronyms. For example, to remember the animal classification system, you can use a mnemonic (acrostic) as shown below *(referring to Figure A.2.1)*.

Acrostic
A mnemonic where the first letter of each word or line helps you remember target information.

Target Info: Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species
Mnemonic: Dear King Please Can Our Family Go Swimming

Animal Classification	Mnemonic
Domain	Dear
Kingdom	King
Phylum	Please
Class	Can
Order	Our
Family	Family
Genus	Go
Species	Swimming

Figure A.2.1: Example of an acrostic. Image created by Sarah Ejaz.

Another example is the big five personality traits. You can use a mnemonic (acronym) to learn the traits as shown below *(referring to Figure A.2.2)*.

Acronym

A mnemonic formed by using the first letter of each word in the target information to create a new word.

Target Info: Openness, Conscientiousness, Extraversion, Agreeableness, Neuroticism
Mnemonic: OCEAN

Personality Traits	Mnemonic
Openness	O
Conscientiousness	C
Extraversion	E
Agreeableness	A
Neuroticism	N

Figure A.2.2: Example of an acrostic. Image created by Sarah Ejaz.

1. Have you ever used mnemonics before?
    - ○ Yes
    - ○ No
2. List the courses or subjects in which you used mnemonics.
3. Describe how you created the mnemonics or create mnemonics if you still use them.
4. Choose the one that applies to you.
    - ○ I prefer mnemonics created by myself over those created by my professor.
    - ○ I prefer mnemonics created by the professor over mine.
    - ○ I do not like using mnemonics.
5. Provide a reason for your choice above.
6. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table A.2.1: Mnemonic use and perception questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I find it easy to create helpful mnemonics on my own.	○	○	○	○	○	○	○
I find it challenging to create useful mnemonics on my own.	○	○	○	○	○	○	○

Table A.2.1 *(continued)*

Question	1	2	3	4	5	6	7
I find mnemonics useful in my study.	○	○	○	○	○	○	○
I find mnemonics helpful in my learning.	○	○	○	○	○	○	○

7. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table A.2.2: Use of mnemonics questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
My use of mnemonics helps me retain learned content long term.	○	○	○	○	○	○	○
My use of mnemonics helps me recall learned information.	○	○	○	○	○	○	○
My use of mnemonics enhances my knowledge.	○	○	○	○	○	○	○
My use of mnemonics helps me pass memorization-intensive courses.	○	○	○	○	○	○	○

8. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table A.2.3: Mnemonic-based tool questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
If a professor in one of my memory-intensive courses provides an interactive tool that makes it easy for me to create mnemonics that enhance my learning and recall, I will use the tool.	○	○	○	○	○	○	○

9. What feature(s) would you like the tool that helps you create your own mnemonics to have?

10. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table A.2.4: Mnemonic-based game questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
If a professor in one of my memory-intensive courses provides an educational game that helps me rehearse retrieval of the target information of the mnemonics that I have created, I will use (play) the game to enhance my learning and recall.	○	○	○	○	○	○	○

11. What feature(s) would you like the educational game that allows you to practice retrieval of the target information using mnemonics to have?

12. Do you spend a lot of time studying but seem to study the "wrong information" for tests?

    ○ Yes

    ○ No

    ○ Sometimes

13. Do you get frustrated when you read because everything seems important?

    ○ Yes

    ○ No

    ○ Sometimes

14. Do you tend to highlight too much when you read textbooks?

    ○ Yes

    ○ No

    ○ Sometimes

15. Do your notes seem excessively long and overly detailed?

    ○ Yes

    ○ No

    ○ Sometimes

16. Do you avoid making study tools such as flashcards because you are not sure what information to put on the study tools?

    ○ Yes

    ○ No

    ○ Sometimes

17. Do you tend to memorize facts or ideas in isolation?

    - ○ Yes
    - ○ No
    - ○ Sometimes

18. When you try to recall information you have studied, do you sometimes feel "lost" because there is no direct way to access the information in your memory?

    - ○ Yes
    - ○ No
    - ○ Sometimes

19. Do you feel that you are memorizing many items of information but not really understanding what they mean or how they are connected?

    - ○ Yes
    - ○ No
    - ○ Sometimes

20. Do you "go blank" on tests when a question asks for information in a form or context different from the way you studied it?

    - ○ Yes
    - ○ No
    - ○ Sometimes

21. Do you lack sufficient time to link difficult information to familiar words or pictures?

    - ○ Yes
    - ○ No
    - ○ Sometimes

22. When you finish reading, do you have difficulty remembering what paragraphs were even about?

    - ○ Yes
    - ○ No
    - ○ Sometimes

23. Do you have difficulty remembering information that appeared in a chart your instructor presented on the chalkboard or on a screen?

    - ○ Yes

- ○ No
- ○ Sometimes

24. Do you find it difficult to recall a visual image of printed information?
    - ○ Yes
    - ○ No
    - ○ Sometimes
25. When you try to recall information, do you rely mainly on words rather than pictures?
    - ○ Yes
    - ○ No
    - ○ Sometimes
26. When your instructor explains a new concept by giving a detailed example or anecdote (story), do you have difficulty recalling the example or anecdote after you leave class?
    - ○ Yes
    - ○ No
    - ○ Sometimes
27. Do you learn individual facts or details without thinking about the schema in which they belong?
    - ○ Yes
    - ○ No
    - ○ Sometimes
28. Do you frequently attempt to use rote memory to memorize facts, definitions, or rules?
    - ○ Yes
    - ○ No
    - ○ Sometimes
29. Do you complete a math problem and immediately move on to the next problem?
    - ○ Yes
    - ○ No
    - ○ Sometimes
30. Do you study information in the same order and in the same form in which it was presented?
    - ○ Yes

- ○ No
- ○ Sometimes

31. Do you avoid creating new study tools that involve reorganizing information?
    - ○ Yes
    - ○ No
    - ○ Sometimes
32. Do you often experience divided attention because too many unrelated thoughts disrupt your thinking?
    - ○ Yes
    - ○ No
    - ○ Sometimes
33. Do you have so many interruptions when you study that you are not quite sure what you have accomplished at the end of a study block?
    - ○ Yes
    - ○ No
    - ○ Sometimes
34. Do you miss important information during a lecture because your mind tends to wander or daydream?
    - ○ Yes
    - ○ No
    - ○ Sometimes
35. When you are reading, do you find it difficult to keep your mind focused on the information in the textbook?
    - ○ Yes
    - ○ No
    - ○ Sometimes
36. Do you study with the television, radio, or stereo turned on?
    - ○ Yes
    - ○ No
    - ○ Sometimes
37. When you review for a test, do you do all or most of your review work silently?

- ○ Yes
- ○ No
- ○ Sometimes

38. Do you have difficulty defining new terminology out loud?

    - ○ Yes
    - ○ No
    - ○ Sometimes

39. Do you have difficulty clearly explaining textbook information to another person?

    - ○ Yes
    - ○ No
    - ○ Sometimes

40. When you rehearse information out loud, do you often feel that your explanations are "fuzzy," unclear, or incomplete?

    - ○ Yes
    - ○ No
    - ○ Sometimes

41. Do you feel awkward or uncomfortable talking out loud to yourself?

    - ○ Yes
    - ○ No
    - ○ Sometimes

42. When you sit down to study, do you set a goal to complete the assignment as quickly as possible?

    - ○ Yes
    - ○ No
    - ○ Sometimes

43. Do you always have the same purpose in mind when you sit down to study?

    - ○ Yes
    - ○ No
    - ○ Sometimes

44. Do you lack curiosity, interest, or enthusiasm in the course content for one or more of your classes?

- ○ Yes
- ○ No
- ○ Sometimes

45. When you begin learning new information, do you find setting a specific learning goal difficult to do?

    - ○ Yes
    - ○ No
    - ○ Sometimes

46. Do you study facts, details, concepts in the same way that you study steps or processes for a procedure?

    - ○ Yes
    - ○ No
    - ○ Sometimes

47. Do you have problems distinguishing between main ideas and individual details in textbook passages?

    - ○ Yes
    - ○ No
    - ○ Sometimes

48. Do you understand general concepts but oftentimes have difficulty giving details that relate to the concept?

    - ○ Yes
    - ○ No
    - ○ Sometimes

49. Do you grasp specific details but oftentimes have difficulty connecting them together to form a larger picture or a concept?

    - ○ Yes
    - ○ No
    - ○ Sometimes

50. Do your lecture notes capture main ideas but lack details?

    - ○ Yes
    - ○ No
    - ○ Sometimes

51. Do your notes include running lists of details without a clear method of showing main ideas?

- ○ Yes
- ○ No
- ○ Sometimes

52. Do you use tests as your main means of getting feedback about what you have learned?

    - ○ Yes
    - ○ No
    - ○ Sometimes

53. Do you use tests as your main means of getting feedback about what you have learned?

    - ○ Yes
    - ○ No
    - ○ Sometimes

54. Do you keep taking in new information without stopping to see whether you are trying to learn too much too fast?

    - ○ Yes
    - ○ No
    - ○ Sometimes

55. When you are rehearsing, do you "keep on going" even if you sense that you have not clearly understood something?

    - ○ Yes
    - ○ No
    - ○ Sometimes

56. Do you tend to use self-quizzing only when you are preparing for a test?

    - ○ Yes
    - ○ No
    - ○ Sometimes

57. If you get feedback that you did not complete a math problem correctly, do you ignore your original answer and try working the problem again?

    - ○ Yes
    - ○ No
    - ○ Sometimes

58. Does information from lectures often seem to be one continuous stream of information without any apparent organization or structure?

    - ○ Yes
    - ○ No
    - ○ Sometimes

59. Do you have difficulty remembering the sequence of important events or the steps of a process?

    - ○ Yes
    - ○ No
    - ○ Sometimes

60. When you try to do a "memory search" to locate information in your memory, are you usually unable to find the information?

    - ○ Yes
    - ○ No
    - ○ Sometimes

61. Do you spend most of your time trying to learn information in the exact order in which it is presented?

    - ○ Yes
    - ○ No
    - ○ Sometimes

62. Do you feel unsure about rearranging, reorganizing, or regrouping information so that it is easier to learn and recall?

    - ○ Yes
    - ○ No
    - ○ Sometimes

63. When your assignment is to read and study a specific chapter, do you spend a lot of time on the assignment so that you will not need to make contact with it again for several weeks?

    - ○ Yes
    - ○ No
    - ○ Sometimes

64. When you are studying, do you often feel as though you are trying to study too much information too quickly?

- ○ Yes
- ○ No
- ○ Sometimes

65. When you study, do you change to a second subject as soon as you complete the assignments for the first subject?

    - ○ Yes
    - ○ No
    - ○ Sometimes

66. Are some of your study blocks more than three hours long?

    - ○ Yes
    - ○ No
    - ○ Sometimes

67. In at least one of your courses, do you spend less time studying that subject than most other students in class do?

    - ○ Yes
    - ○ No
    - ○ Sometimes

68. Once you have completed an assignment, do you put it aside until close to the time of the next test?

    - ○ Yes
    - ○ No
    - ○ Sometimes

69. Do you have problems remembering or recalling information that you know you learned several weeks earlier?

    - ○ Yes
    - ○ No
    - ○ Sometimes

70. Do you need to add more review time to your weekly study schedule?

    - ○ Yes
    - ○ No
    - ○ Sometimes

71. Do you study fewer than two hours per week for every one hour in class?

    - ○ Yes
    - ○ No
    - ○ Sometimes

72. Do you sit down to study and feel that you are all caught up and have nothing to study?

    - ○ Yes
    - ○ No
    - ○ Sometimes

73. Rank the following list from 1 to 4, with 1 representing the one that describes you the best and 4 representing you the least.

Table A.2.5: Learning style questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**
Visual Learning Style: I learn best through visual. I like to view information in a graphical format such as charts, diagrams, maps, and infographics.	○	○	○	○
Auditory Learning Style: I learn best by listening. I like listening to lectures, audio books, podcasts and participating in group discussions.	○	○	○	○
Reading/Writing Learning Style: I learn best by reading and writing. I like interacting with written words, including taking notes, reading textbooks, and writing essays.	○	○	○	○
Kinesthetic Learning Style: I learn best by doing. I like to physically engage with the material, e.g., through lab experiments, simulations, and hands-on assignments.	○	○	○	○

74. What is your gender?

    - ○ Male
    - ○ Female
    - ○ Other

75. What is your age?

    - ○ 18 - 24 years old
    - ○ 25 - 34 years old
    - ○ 35 - 44 years old

- 45 - 54 years old
- 54+ years old

76. What year of study are you in?

    - 1st year
    - 2nd year
    - 3rd year
    - 4th year
    - Master's
    - PhD
    - Other

77. What is your course of study?

    - Computer Science
    - Psychology
    - Biology
    - Other

78. Which race or ethnicity best describes you?

    - African/Black (including African-American, African-Canadian, Caribbean)
    - East Asian (e.g., Chinese, Taiwanese, Japanese, Korean, etc.)
    - European/White
    - Indo-Caribbean, Indo-African, Indo-Fijian, West-Indian
    - Latin, South or Central American
    - Polynesian (e.g., Samoans, Tongan, Niuean, Cook Island Maori, Tahitian Maaohi, Hawaiian Ma'oli, Marquesan, New Zealand Maori)
    - South Asian (e.g., Afghan, Nepali, Tamil, Bangladeshi, Pakistani, Indian, Sri Lankan, Punjabi)
    - Southeast Asian (e.g., Vietnamese, Thai, Cambodian, Malaysian, Filipino/a, Laotian, Singaporean, Indonesian)
    - West Asian (e.g., Iraqi, Jordanian, Palestinian, Saudi, Syrian, Yemeni, Armenian, Iranian, Israeli, Turkish)
    - Indigenous within Canada (e.g., First Nation, Métis, Inuit)
    - Other

79. What type of student do you consider yourself on the average?

- ○ <50%
- ○ 51-60%
- ○ 61-70%
- ○ 71-80%
- ○ 81-90%
- ○ 91-100%
- ○ I prefer not to answer

If you are doing this survey in-person, you may have received a participant code. Please enter the participant code below.

If you have not received a participant code, please use any 6 character code of your liking. (You should NOT use simple or predictable codes such as "123abc", "abc123", "123456", "abcdef", or any similar variations. Choose a code that is unique and not based on obvious patterns.)

Please remember this code or note it down as you will be asked to enter it in Part 2 and Part 3.

80. Enter participant code here.

A.3 Part 2

Survey

81. Please enter your participant code. If you have not been assigned one, use the code you generated in Part 1.

    Acrostic definition and example:

Acrostic
A mnemonic where the first letter of each word or line helps you remember target information.

Target Info: Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species
Mnemonic: Dear King Please Can Our Family Go Swimming

Animal Classification	Mnemonic
Domain	Dear
Kingdom	King
Phylum	Please
Class	Can
Order	Our
Family	Family
Genus	Go
Species	Swimming

Figure A.3.3: Example of an acrostic. Image created by Sarah Ejaz.

Creating Your Own Mnemonics

Now that you've learned about mnemonics, it's time for you to create your own!

Types of Interview Questions

When it comes to asking questions in an interview, the broad types of questions can be as follows.

Background: help identify characteristics of a person in relation to other people

Behaviors: questions about what a person does or has done

Sensory: to understand how a person utilizes their senses in a situation

Knowledge: discovering the factual information known by a person

Feeling: understanding the emotional responses of a person

Opinion: figuring out a person's interpretations and cognitive processes

(Reference: `https://people.ucsc.edu/~ktellez/Pattonch51987.pdf`)

82. Create an acrostic mnemonic that will help you recall the **6 Types of Interview Questions** (Background, Behaviors, Sensory, Knowledge, Feeling, Opinion). The acrostic should be a meaningful sentence, such as "**Dear King Please Can Our Family Go Swimming**" to remember the animal classification system above.

A.4 Part 3

Survey

83. Please enter your participant code. If you have not been assigned one, use the code you generated in Part 1.

    Acrostic definition and example:

Acrostic
A mnemonic where the first letter of each word or line helps you remember target information.

Target Info: Domain, Kingdom, Phylum, Class, Order, Family, Genus, Species
Mnemonic: Dear King Please Can Our Family Go Swimming

Animal Classification	Mnemonic
Domain	Dear
Kingdom	King
Phylum	Please
Class	Can
Order	Our
Family	Family
Genus	Go
Species	Swimming

Figure A.4.4: Example of an acrostic. Image created by Sarah Ejaz.

Creating Your Own Mnemonics

Now that you've learned about mnemonics, it's time for you to create your own!

Norman's Design Principles

Norman's design principles are 7 principles proposed by Don Norman, used to design products efficiently and effectively.

Discoverability: increases understanding of the available options and where to perform them.

Feedback: communicates the response to our actions or the status of systems.

Conceptual-models: are simple explanations of how something works.

Affordance: is the perceived action of an object.

Signifiers: tell us exactly where to act.

Mapping: is the relationship between the controls and the effect they have.

Constraints: help restrict the kind of interactions that can take place.

(Reference: `https://uxdesign.cc/ux-psychology-principles-seven-fundamental-design-principles-39c420a05f84`)

84. Create an acrostic mnemonic that will help you recall **Norman's Design Principles** (Discoverability, Feedback, Conceptual-models, Affordance, Signifiers, Mapping, Constraints). The acrostic should be a meaningful sentence, such as "**Dear King Please Can Our Family Go Swimming**" to remember the animal classification system above.

85. Thank you for completing the survey! To receive your $10 compensation, please enter your email address OR your phone number for Interac transfer (optional).

B Appendix B: Experiment Study Instruments

B.1 Screening Survey

Consent Form

Study Name: Designing Educational Tools to Promote Learning in University Classrooms - Screening Survey

Note: This is a screening to assess your eligibility to participate in the study. You will be contacted if you are eligible for recruitment.

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. The research explores whether using a tool will help with learning taught content.

What You Will Be Asked to Do in the Research: You are required to provide your answers to the questions in the questionnaire. You will also be asked to provide key demographic information such as education in the questionnaire.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You:

The benefit of the research is that you will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $50 if you are asked to participate in the research.

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the total $50 compensation, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a password-protected Google Drive The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo @yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail: ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. What year of study are you in?

    - ○ 1st year
    - ○ 2nd year
    - ○ 3rd year
    - ○ 4th year
    - ○ Master's
    - ○ PhD

2. What is your course of study?

- ○ Computer Science
- ○ Psychology
- ○ Biology
- ○ Other

3. Have you studied any biology-based subject at undergraduate or any higher education level? If yes, please specify. If not, please write N/A.

4. Please enter your email if you are interested in participating in the study. If you are eligible, we'll reach out to you to schedule the experiment.

B.2 Part 1

Consent Form (for both Control and Experimental Groups)

Study Name: Designing Educational Tools to Promote Learning in University Classrooms

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. The research explores whether using a tool will help with learning taught content.

What You Will Be Asked to Do in the Research: This is a 2-part study. The first part includes a video lecture followed by revision and then a quiz. This session will be 1 hour and 50 minutes long. For the second part, you will be asked to return after 1 week to perform the same experiment but with another subject. The second part will be 1 hour and 55 minutes long and you will be provided with a separate consent form for the session.

Experiment Part 1

First, you will be shown a video lecture (10 minutes) about topics related to an undergraduate-level course. Then you will be allowed to review the lecture for 45 minutes. After that, you will be given a quiz based on the video lecture shown to you to complete in 45 minutes. You will also be asked to return 1 week later for the follow-up experiment.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You:

Experiment Part 1

The benefit of the research is that you will learn a new method to memorize content for academic courses and gain insight into how research for such methods is conducted. You will also learn biology concepts through the video lecture.

You will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $50 in total for this experiment (parts 1 and 2).

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the total $50 compensation, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a password-protected Google Drive The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo @yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engi-

neering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail: ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My selection below indicates my consent.
   - ○ Yes
   - ○ No
2. I understand that my de-identified data will be placed into an open research data repository.
   - ○ Yes
   - ○ No
3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any comments made during the experiment.
   - ○ Yes
   - ○ No

Demographics Survey (Control Group)

Section 1: Consent Form

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of mnemonics used in tools for learning course material. The research explores whether using a tool will help with learning mnemonics.

What You Will Be Asked to Do in the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. You will be asked to provide your demographics.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You: The benefit of the research is that you will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $10.

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the $10 for agreeing to be in the project, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a password-protected Google Drive. The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Please note that the survey is being conducted with the help of Google Forms, a company not affiliated with York University and with its own privacy and security policies that you can find at https://transparency.google/our-policies/product-terms/google-forms/. There is always a risk during web-based transmission that

data can be intercepted by a third party (e.g., government agencies, hackers) and thus confidentiality and privacy cannot be guaranteed.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo @yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My choice below indicates my consent.
    - ○ Yes
    - ○ No
2. I understand that my de-identified data will be placed into an open research data repository.
    - ○ Yes
    - ○ No
3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any responses—whether brief or detailed—provided in the open-ended sections of the survey.
    - ○ Yes
    - ○ No

Section 2: Demographics

1. What is your gender?
    - ○ Male
    - ○ Female
    - ○ Other
2. What is your age?
    - ○ 18 - 24 years old
    - ○ 25 - 34 years old

- 35 - 44 years old
- 45 - 54 years old
- 54+ years old

3. What year of study are you in?
    - 1st year
    - 2nd year
    - 3rd year
    - 4th year
    - Master's
    - PhD
    - Other
4. What is your course of study?
    - Computer Science
    - Psychology
    - Biology
    - Other
5. Which race or ethnicity best describes you?
    - African/Black (including African-American, African-Canadian, Caribbean)
    - East Asian (e.g., Chinese, Taiwanese, Japanese, Korean, etc.)
    - European/White
    - Indo-Caribbean, Indo-African, Indo-Fijian, West-Indian
    - Latin, South or Central American
    - Polynesian (e.g., Samoans, Tongan, Niuean, Cook Island Maori, Tahitian Maaohi, Hawaiian Ma'oli, Marquesan, New Zealand Maori)
    - South Asian (e.g., Afghan, Nepali, Tamil, Bangladeshi, Pakistani, Indian, Sri Lankan, Punjabi)
    - Southeast Asian (e.g., Vietnamese, Thai, Cambodian, Malaysian, Filipino/a, Laotian, Singaporean, Indonesian)
    - West Asian (e.g., Iraqi, Jordanian, Palestinian, Saudi, Syrian, Yemeni, Armenian, Iranian, Israeli, Turkish)
    - Indigenous within Canada (e.g., First Nation, Métis, Inuit)
    - Other

6. What type of student do you consider yourself on the average?

   - ○ <50%
   - ○ 51-60%
   - ○ 61-70%
   - ○ 71-80%
   - ○ 81-90%
   - ○ 91-100%
   - ○ I prefer not to answer

Section 3: Participant Code

7. Enter participant code here.

UX Survey: SAVE Tool (Experimental Group)

Section 1: Consent Form

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. You will be asked to assess the user experience (UX) of the one of the educational tools, the SAVE Tool, as well as some questions regarding the usage of mnemonics.

What You Will Be Asked to Do in the Research: You are required to provide your answers to the questions in the survey.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You: The benefit of the research is that you will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $10.

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have

with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the $10 for agreeing to be in the project, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

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Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo @yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

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of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My choice below indicates my consent.
   - ○ Yes
   - ○ No
2. I understand that my de-identified data will be placed into an open research data repository.
   - ○ Yes
   - ○ No
3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any responses—whether brief or detailed—provided in the open-ended sections of the survey.
   - ○ Yes
   - ○ No
4. Enter participant code here.

Section 2: User Experience

1. Q1: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.1: Q1 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I find the steps to use the SAVE Tool easy to follow	○	○	○	○	○	○	○
The SAVE Tool was confusing to use	○	○	○	○	○	○	○

2. Q2: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.2: Q2 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the SAVE Tool useful to learn memory-intensive course content	○	○	○	○	○	○	○
The SAVE Tool will help me to prepare for memory-intensive course exams	○	○	○	○	○	○	○

3. Q3: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.3: Q3 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I found using the SAVE Tool enjoyable	○	○	○	○	○	○	○
I did not find using the SAVE Tool fun	○	○	○	○	○	○	○

4. Q4: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.4: Q4 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
The SAVE Tool is trustworthy	○	○	○	○	○	○	○
I think the SAVE Tool does not have my best interest in mind	○	○	○	○	○	○	○

5. Q5: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.5: Q5 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
The features of the SAVE Tool convince me to adopt it to study for a memory-intensive course exam	○	○	○	○	○	○	○
The features of the SAVE Tool motivate me to use it in my future memory-intensive courses	○	○	○	○	○	○	○

6. Q6: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.6: Q6 questions 1 (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
If a professor in one of my memory-intensive courses provides an interactive tool that makes it easy for me to create mnemonics that enhance my learning and recall, I will use the tool.	○	○	○	○	○	○	○

7. What feature from the SAVE Tool do you like the most?
8. Why do you like the feature chosen above?
9. What new feature would you like the SAVE Tool to have?
10. Why did you suggest that feature?
11. Have you ever used mnemonics before?

12. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.2.7: Time- and instruction manual-based questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I depended on the instruction manual to create the Big Five Personality Traits mnemonic in the SAVE Tool.	○	○	○	○	○	○	○
I depended on the instruction manual to view the Big Five Personality Traits mnemonic in the SAVE Tool.	○	○	○	○	○	○	○
I had enough time to create and learn the mnemonics using the SAVE Tool.	○	○	○	○	○	○	○

Section 3: Demographics

1. What is your gender?
    - ○ Male
    - ○ Female
    - ○ Other
2. What is your age?
    - ○ 18 - 24 years old
    - ○ 25 - 34 years old
    - ○ 35 - 44 years old
    - ○ 45 - 54 years old
    - ○ 54+ years old
3. What year of study are you in?
    - ○ 1st year
    - ○ 2nd year
    - ○ 3rd year
    - ○ 4th year
    - ○ Master's
    - ○ PhD
    - ○ Other
4. What is your course of study?
    - ○ Computer Science

- ○ Psychology
- ○ Biology
- ○ Other

5. Which race or ethnicity best describes you?

   - ○ African/Black (including African-American, African-Canadian, Caribbean)
   - ○ East Asian (e.g., Chinese, Taiwanese, Japanese, Korean, etc.)
   - ○ European/White
   - ○ Indo-Caribbean, Indo-African, Indo-Fijian, West-Indian
   - ○ Latin, South or Central American
   - ○ Polynesian (e.g., Samoans, Tongan, Niuean, Cook Island Maori, Tahitian Maaohi, Hawaiian Ma'oli, Marquesan, New Zealand Maori)
   - ○ South Asian (e.g., Afghan, Nepali, Tamil, Bangladeshi, Pakistani, Indian, Sri Lankan, Punjabi)
   - ○ Southeast Asian (e.g., Vietnamese, Thai, Cambodian, Malaysian, Filipino/a, Laotian, Singaporean, Indonesian)
   - ○ West Asian (e.g., Iraqi, Jordanian, Palestinian, Saudi, Syrian, Yemeni, Armenian, Iranian, Israeli, Turkish)
   - ○ Indigenous within Canada (e.g., First Nation, Métis, Inuit)
   - ○ Other

6. What type of student do you consider yourself on the average?

   - ○ <50%
   - ○ 51-60%
   - ○ 61-70%
   - ○ 71-80%
   - ○ 81-90%
   - ○ 91-100%
   - ○ I prefer not to answer

B.3 Part 2

Consent Form

Study Name: Designing Educational Tools to Promote Learning in University Classrooms

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. The research explores whether using a tool will help with learning taught content.

What You Will Be Asked to Do in the Research: You will be given a quiz to attempt related to the video lecture you viewed a week prior to this experiment. You have a total of 45 minutes to complete the quiz. After you complete the quiz, you will revise the content using the same method you used in the previous part of this experiment for 15 minutes. You will then be given another quiz, which will take 45 minutes to complete.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You: The benefit of the research is that you will learn a new method to memorize content for academic courses and gain insight into how research for such methods is conducted.

You will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive $50 in total for this experiment (parts 1 and 2).

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the total $50 compensation, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a

password-protected Google Drive The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo@yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail: ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My selection below indicates my consent.

    - ○ Yes
    - ○ No

2. I understand that my de-identified data will be placed into an open research data repository.

    - ○ Yes
    - ○ No

3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any comments made during the experiment.

    - ○ Yes
    - ○ No

Debriefing Consent Form

After completing the first part of this experiment, I was asked to return 1 week later for a follow-up experiment. I was not told about the exact contents of the follow-up experiment, which consisted of a quiz about the lecture material from the first part of the experiment, a revision session, and then a second quiz about the lecture material. This was due to the researchers not wanting me to revise the material of the lecture to quiz if I was able to retain what I learned from the lecture without revision and then see if revision had any effect on the second quiz results. I also had a debriefing session with the researcher(s) during which I was allowed to ask any questions I had about the deception.

During the debriefing session, I learned that it was necessary for the researchers to disguise the real purpose of this study. I realize that this was necessary since having full information about the actual purpose of the study might have influenced the way in which I responded to the tasks, and this would have invalidated the results. Thus, to ensure that this did not happen, some of the details about the purpose of the study initially were not provided (or were provided in a manner that slightly misrepresented the real purpose of the study). However, I have now received a complete verbal and written explanation as to the actual purpose of the study, i.e., information about the follow-up experiment being withheld so that I avoid revising the lecture material to impact my answers in the follow-up experiment and have had an opportunity to ask any questions about this and to receive acceptable answers to my questions.

I have been asked to give permission for the researchers to use my data (or information I provided) in their study and agree to this request. I am aware that I may withdraw this consent by notifying the Principal Investigator.

This study has been reviewed and received ethics clearance through the Human Participants Review Committee (HPRC). If you have questions for the Committee, contact the Manager, Research Ethics, Office of Research Ethics, at ore@yorku.ca.

For all other questions, contact Dr. Kiemute Oyibo at kiemute.oyibo@yorku.ca.

4. I understand the debriefing and why it was necessary for the researchers to disguise the real purpose of the study.

    - ○ Yes
    - ○ No

Exit Survey (Control Group)

Section 1: Participant Code

1. Enter participant code here.

Section 2: Familiarity with Concepts

2. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.1: Familiarity with concepts questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I knew the topic, **Krebs Cycle Substrates**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Krebs Cycle Reactions**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Cranial Nerves**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Cranial Nerve Functions**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Biological Organization Levels**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Biological Organization Disciplines**, prior to taking the experiment	○	○	○	○	○	○	○

3. After Part 1 of the experiment, did you look up the topics from the video lecture shown to you during the experiment?

   ○ Yes

   ○ No

   ○ Maybe

Section 3: Mnemonics

4. Are you familiar with the learning strategy, mnemonics, e.g., acronym, acrostic, etc.? Examples include ROYGBIV (acronym) and Richard of York Gave Battle In Vain (acrostic) representing the rainbow colors (Red Orange Yellow Green Blue Indigo Violet).

   ○ Yes

   ○ No

   ○ Somewhat

5. During your preparation for the quiz, did you use any of these types of mnemonics or other types when trying to learn the target topics and information in the "Biology Intro" module. If yes, which? If no, type N/A.

6. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.2: Mnemonics questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
If a professor in one of my memory-intensive courses provides an interactive tool that makes it easy for me to create mnemonics that enhance my learning and recall, I will use the tool.	○	○	○	○	○	○	○
If a professor in one of my memory-intensive courses provides an educational game that helps me rehearse retrieval of the target information of the mnemonics that I have created, I will use (play) the game to enhance my learning and recall.	○	○	○	○	○	○	○

Section 2: User Experience

Thank you for completing the experiment. As part of our efforts in designing effective educational tools for instructors and students, we would like to know what your thoughts are about the current Learning Management System (eClass) at YorkU.

1. Q1:

Table B.3.3: Q1 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I find the steps to use eClass easy to follow	○	○	○	○	○	○	○
eClass is confusing to use	○	○	○	○	○	○	○

2. Q2:

Table B.3.4: Q2 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I find eClass useful to learn memory-intensive course content	○	○	○	○	○	○	○
eClass will help me to prepare for memory-intensive course exams	○	○	○	○	○	○	○

3. Q3:

Table B.3.5: Q3 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I find using eClass enjoyable	○	○	○	○	○	○	○

Table B.3.5 *(continued)*

Question	1	2	3	4	5	6	7
I do not find using eClass fun	○	○	○	○	○	○	○

4. Q4:

Table B.3.6: Q4 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
eClass is trustworthy	○	○	○	○	○	○	○
I think eClass does not have my best interest in mind	○	○	○	○	○	○	○

5. Q5:

Table B.3.7: Q5 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
The features of eClass convince me to adopt it to study for a memory-intensive course exam	○	○	○	○	○	○	○
The features of eClass motivate me to use it in my future memory-intensive courses	○	○	○	○	○	○	○

6. What feature from eClass do you like the most?
7. Why do you like the feature chosen above?
8. What new feature would you like eClass to have?
9. Why did you suggest that feature?
10. How many days after Part 1 did you do Part 2? (e.g. doing Part 1 on a Monday and doing Part 2 on the next Monday, you would say 7 days.)

Exit Survey (Experimental Group)

Consent Form

Study Name: Designing Educational Tools to Promote Learning in University Classrooms

Researchers:

Kiemute Oyibo, Assistant Professor, Lassonde School of Engineering Research Center, York University, 4751 Keele Street, Toronto, Ontario, M3J 2N9, LRC 133, 416-736-2100, kiemute.oyibo@yorku.ca. (PI)

Sarah Ejaz, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, sejaz@yorku.ca.

Kingson Fung, Graduate Student, Lassonde School of Engineering, York University, Toronto, Ontario, kingson2@yorku.ca.

Purpose of the Research: The aim of the research is to assess the effectiveness of using educational tools that deploy varying learning techniques for learning course material. You will be asked to reassess the user experience (UX) of the one of the educational tools, the SAVE Tool, as well as some questions regarding the usage of mnemonics.

What You Will Be Asked to Do in the Research: You are required to provide your answers to the questions in the survey.

Risks and Discomforts: We do not foresee any risks or discomfort from your participation in the research.

Benefits of the Research and Benefits to You:

The benefit of the research is that you will have the opportunity to access the findings by making a request to the researchers. The findings will help advance research in discovering innovative ways for students to learn taught material. You will also receive in total $50 for completing the study.

Voluntary Participation and Withdrawal: Your participation in the study is completely voluntary and you may choose to stop participating at any time. Your decision not to volunteer, to stop participating, or to refuse to answer particular questions will not influence the nature of the ongoing relationship you may have with the researchers or study staff, or the nature of your relationship with York University either now, or in the future.

If you stop participating, you will still be eligible to receive the total $50 compensation, even if you withdraw without completion of the research. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible. Should you wish to withdraw after the study, you will have the option to also withdraw your data up until the analysis is complete.

Confidentiality: Unless you choose otherwise all information you supply during the research will be held in confidence and unless you specifically indicate your consent, your name will not appear in any report or publication of the research.

Your data will be stored on password protected devices and only research staff/research team members will have access to this information. Your data will be anonymized using a participant code to connect the data from the first and second components of the study. Furthermore, data will be encrypted and stored on a password-protected Google Drive The data collected in this research project may be used – anonymized data – by members of the research team in subsequent research investigations exploring similar lines of inquiry. Such projects will still undergo ethics review by the HPRC, our institutional REB. Any secondary use of anonymized data by the research team will be treated with the same degree of confidentiality and anonymity as in the original research project. Confidentiality will be provided to the fullest extent possible by law.

You will be asked to provide your contact information, i.e. email address, to issue you your compensation for participating in this study. This information will not be uploaded to a data repository to protect your anonymity. After confirmation from your end of the compensation being received, your contact information will be deleted.

Please note that at the end of the study, anonymized data may be deposited into one or more publicly

accessible scientific repositories, such as York University Dataverse, so that data may be inspected and analyzed by other researchers. If data is not identifiable, the data that will be shared on York University Dataverse will not contain any information that can identify you.

Questions About the Research? If you have questions about the research in general or about your role in the study, please feel free to contact the principal investigator (Dr. Kiemute Oyibo) at kiemute.oyibo @yorku.ca. You may also contact the Department of Electrical Engineering & Computer Science and Engineering at eecs-ug@yorku.ca and/or 416-736-5053.

This research has received ethics review and approval by the Human Participants Review Sub-Committee (**#e2025-116**), York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. If you have any questions about this process, or about your rights as a participant in the study, please contact the Manager, Research Ethics in the Office of Research Ethics, York University (e-mail: ore@yorku.ca). This office oversees the ethical conduct of research studies and is not part of the study team. Everything that you discuss will be kept confidential.

1. I consent to participate in this study conducted by Kiemute Oyibo, Sarah Ejaz, and Kingson Fung. I have understood the nature of this project and wish to participate. I am not waiving any of my legal rights by signing this form. My selection below indicates my consent.
   - ○ Yes
   - ○ No
2. I understand that my de-identified data will be placed into an open research data repository.
   - ○ Yes
   - ○ No
3. I consent to the use of quotations in any final reports/ publications of the research. Quotations include any comments made during the experiment.
   - ○ Yes
   - ○ No
4. Enter participant code here.

Section 2: Familiarity with Concepts

1. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.8: Familiarity with concepts in exit survey for Experimental group (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I knew the topic, **Krebs Cycle Substrates**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Krebs Cycle Reactions**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Cranial Nerves**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Cranial Nerve Functions**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Biological Organization Levels**, prior to taking the experiment	○	○	○	○	○	○	○
I knew the topic, **Biological Organization Disciplines**, prior to taking the experiment	○	○	○	○	○	○	○

2. After Part 1 of the experiment, did you look up the topics from the video lecture shown to you during the experiment?

   ○ Yes

   ○ No

   ○ Maybe

Section 3: Mnemonics

3. Are you familiar with the learning strategy, mnemonics, e.g., acronym, acrostic, etc.? Examples include ROYGBIV (acronym) and Richard of York Gave Battle In Vain (acrostic) representing the rainbow colors (Red Orange Yellow Green Blue Indigo Violet).

   ○ Yes

   ○ No

   ○ Somewhat

4. During your preparation for the quiz, did you use any other learning strategies than the mnemonics provided when trying to learn the target topics and information in the "Biology Intro" module. If yes, which? If no, type N/A.

5. During your preparation for the quiz, did you use any of type of mnemonics that you created yourself when trying to learn the target topics and information in the "Biology Intro" module? If you used the mnemonics provided to you in the SAVE Tool, write N/A.

6. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.9: Mnemonic-based tool and game questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
If a professor in one of my memory-intensive courses provides an interactive tool that makes it easy for me to create mnemonics that enhance my learning and recall, I will use the tool.	○	○	○	○	○	○	○
If a professor in one of my memory-intensive courses provides an educational game that helps me rehearse retrieval of the target information of the mnemonics that I have created, I will use (play) the game to enhance my learning and recall.	○	○	○	○	○	○	○

7. Q1: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.10: Q1 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I find the steps to use the SAVE Tool easy to follow	○	○	○	○	○	○	○
The SAVE Tool was confusing to use	○	○	○	○	○	○	○

8. Q2: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.11: Q2 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found the SAVE Tool useful to learn memory-intensive course content	○	○	○	○	○	○	○
The SAVE Tool will help me to prepare for memory-intensive course exams	○	○	○	○	○	○	○

9. Q3: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.12: Q3 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	**1**	**2**	**3**	**4**	**5**	**6**	**7**
I found using the SAVE Tool enjoyable	○	○	○	○	○	○	○
I did not find using the SAVE Tool fun	○	○	○	○	○	○	○

10. Q4: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.13: Q4 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
The SAVE Tool is trustworthy	○	○	○	○	○	○	○
I think the SAVE Tool does not have my best interest in mind	○	○	○	○	○	○	○

11. Q5: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.14: Q5 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
The features of the SAVE Tool convince me to adopt it to study for a memory-intensive course exam	○	○	○	○	○	○	○
The features of the SAVE Tool motivate me to use it in my future memory-intensive courses	○	○	○	○	○	○	○

12. Q6: Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.15: Q6 questions (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
If a professor in one of my memory-intensive courses provides an interactive tool that makes it easy for me to create mnemonics that enhance my learning and recall, I will use the tool.	○	○	○	○	○	○	○

13. What feature from the SAVE Tool do you like the most?
14. Why do you like the feature chosen above?
15. What new feature would you like the SAVE Tool to have?
16. Why did you suggest that feature?
17. Answer the following questions on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree).

Table B.3.16: Time-based question (1 = Strongly Disagree, 7 = Strongly Agree)

Question	1	2	3	4	5	6	7
I had enough time to revise the mnemonics using the SAVE Tool.	○	○	○	○	○	○	○

18. How many days after Part 1 did you do Part 2? (e.g. doing Part 1 on a Monday and doing Part 2 on the next Monday, you would say 7 days.)

B.4 Quiz

Quiz X.1 (where X = 1, 2, and 3 based on time point in experiment)

Title: Biology 101 Quiz X.1 *(where X = 1, 2, and 3 based on time point in experiment)*

Please proceed with the Biology 101 quiz. Answer the questions to the best of your ability. At the end of the quiz, you will be provided with a link to the next part of the quiz.

Section 1: Participant Code

1. Enter participant code here. Please feel free to ask researcher in case of any confusion.

Section 2: Short Questions - Cranial Nerves

List the 12 cranial nerves.

If you do not recall the cranial nerve, type N/A.

2. Cranial Nerve #1
3. Cranial Nerve #2
4. Cranial Nerve #3
5. Cranial Nerve #4
6. Cranial Nerve #5
7. Cranial Nerve #6
8. Cranial Nerve #7
9. Cranial Nerve #8
10. Cranial Nerve #9
11. Cranial Nerve #10
12. Cranial Nerve #11
13. Cranial Nerve #12

Section 3: Short Questions - Cranial Nerve Functions

List the 12 cranial nerve functions.

If you do not recall the cranial nerve function, type N/A.

14. Cranial Nerve Function #1
15. Cranial Nerve Function #2
16. Cranial Nerve Function #3

17. Cranial Nerve Function #4
18. Cranial Nerve Function #5
19. Cranial Nerve Function #6
20. Cranial Nerve Function #7
21. Cranial Nerve Function #8
22. Cranial Nerve Function #9
23. Cranial Nerve Function #10
24. Cranial Nerve Function #11
25. Cranial Nerve Function #12

Section 4: Short Questions - Biological Organization Levels

List the 12 levels of biological organization from the simplest to the most complex.

If you do not recall the biological organization level, type N/A.

26. Biological Organization Level #1
27. Biological Organization Level #2
28. Biological Organization Level #3
29. Biological Organization Level #4
30. Biological Organization Level #5
31. Biological Organization Level #6
32. Biological Organization Level #7
33. Biological Organization Level #8
34. Biological Organization Level #9
35. Biological Organization Level #10
36. Biological Organization Level #11
37. Biological Organization Level #12

Section 5: Short Questions - Biological Organization Levels: Disciplines

List the 12 disciplines of the levels of biological organization.

If you do not recall the discipline of the biological organization level, type N/A.

38. Biological Organization Level: Discipline #1
39. Biological Organization Level: Discipline #2
40. Biological Organization Level: Discipline #3
41. Biological Organization Level: Discipline #4
42. Biological Organization Level: Discipline #5
43. Biological Organization Level: Discipline #6
44. Biological Organization Level: Discipline #7
45. Biological Organization Level: Discipline #8
46. Biological Organization Level: Discipline #9
47. Biological Organization Level: Discipline #10
48. Biological Organization Level: Discipline #11
49. Biological Organization Level: Discipline #12

Section 6: Short Questions - Krebs Cycle Substrates

List the 9 substrates produced at each step of the Krebs cycle in order.

If you do not recall the substrate, type N/A.

50. Krebs Cycle Substrate #1
51. Krebs Cycle Substrate #2
52. Krebs Cycle Substrate #3
53. Krebs Cycle Substrate #4
54. Krebs Cycle Substrate #5
55. Krebs Cycle Substrate #6
56. Krebs Cycle Substrate #7
57. Krebs Cycle Substrate #8
58. Krebs Cycle Substrate #9

Section 7: Short Questions - Krebs Cycle Reactions

List the 8 reactions that occur at each step of the Krebs cycle in order.

If you do not recall the reaction, type N/A.

59. Krebs Cycle Reaction #1
60. Krebs Cycle Reaction #2
61. Krebs Cycle Reaction #3
62. Krebs Cycle Reaction #4
63. Krebs Cycle Reaction #5
64. Krebs Cycle Reaction #6
65. Krebs Cycle Reaction #7
66. Krebs Cycle Reaction #8
67. Krebs Cycle Reaction #9

Quiz X.2 (where X = 1, 2, and 3 based on time point in experiment)

Title: Biology 101 Quiz X.2 *(where X = 1, 2, and 3 based on time point in experiment)*

Please proceed with the Biology 101 quiz. Answer the questions to the best of your ability.

Section 1: Participant Code

1. Enter participant code here. Please feel free to ask researcher in case of any confusion.

Section 2: Cranial Nerves

2. Cranial nerves play roles in all EXCEPT:
    - Digesting food
    - Smelling
    - Seeing
    - Moving the face
3. Where are the cranial nerves located in the nervous system?
    - Peripheral nervous system
    - Central nervous system
    - Autonomic nervous system
    - Somatic nervous system
4. Which of these is TRUE about cranial nerves?
    - They transmit sensory and motor information between the brain and upper body
    - They originate in the spinal cord
    - They control digestion

- They mostly regulate hormone release

5. Which cranial nerve does not originate from the brain?
    - Accessory nerve
    - Optic nerve
    - Facial nerve
    - Trigeminal nerve

Section 3: Cranial Nerve Functions

6. The glossopharyngeal nerve is best described as:
    - Sensory and Motor
    - Motor
    - Sensory
    - Autonomic
7. Which function does the hypoglossal nerve serve?
    - Motor
    - Sensory
    - Motor and Sensory
    - Autonomic
8. The vestibulocochlear nerve has what type of function?
    - Sensory
    - Motor
    - Sensory and Motor
    - Autonomic
9. The trochlear nerve is primarily responsible for:
    - Motor control
    - Taste
    - Smell
    - Balance

Section 4: Biological Organization Levels

10. Which level describes a single living being made of organ systems?

- ○ Organism
- ○ Organ
- ○ Tissue
- ○ Population

11. What is a group of different species living together in one place?

- ○ Community
- ○ Population
- ○ Organism
- ○ Biosphere

12. What do you call a group of organisms of the same species in one area?

- ○ Population
- ○ Community
- ○ Ecosystem
- ○ Organism

13. Which level includes specialized structures within a cell?

- ○ Organelle
- ○ Tissue
- ○ Molecule
- ○ Organ

Section 5: Biological Organization Disciplines

14. Which discipline studies groups of similar cells?

- ○ Histology
- ○ Anatomy
- ○ Cellular Biology
- ○ Ecology

15. Which field studies organelles like mitochondria and chloroplasts?

- ○ Cellular Biology
- ○ Histology
- ○ Anatomy
- ○ Molecular Biology

16. Which discipline studies groups of the same species in one area?

    - Population Biology
    - Community Biology
    - Histology
    - Cellular Biology

17. Which discipline focuses on systems like the respiratory system?

    - Physiology
    - Anatomy
    - Ecology
    - Molecular Biology

Section 6: Krebs Cycle Substrates

18. What is required for the cycle to repeat?

    - Regeneration of Oxaloacetate
    - Production of FADH2
    - Release of CO2
    - Presence of Malate

19. Which substrate is the direct precursor to Malate?

    - Fumarate
    - Succinate
    - Citrate
    - a-Ketogluterate

20. What is a key byproduct when Isocitrate is oxidized?

    - Citrate
    - FADH2
    - ATP
    - CO2

21. What is the product of the hydration of Fumarate?

    - Malate
    - Oxaloacetate

- Citrate
- Succinyl-CoA

Section 7: Krebs Cycle Reactions

22. Which step produces ATP?
    - Oxidation of Isocitrate
    - Conversion of Malate to Oxaloacetate
    - Conversion of Succinyl-CoA to Succinate
    - Formation of Citrate from Acetyl-CoA
23. What transformation happens when Succinate becomes Fumarate?
    - Oxidation
    - Isomerization
    - Hydration
    - Decarboxylation
24. What happens to Malate in Step 8?
    - It is oxidized to regenerate Oxaloacetate
    - It undergoes phosphorylation to form ATP
    - It is hydrated to form Citrate
    - It is decarboxylated to produce Fumarate
25. What happens to Succinyl-CoA in Step 5?
    - It is phosphorylated to produce Succinate and ATP
    - It is oxidized to produce NADH
    - It undergoes hydration to form Malate
    - It combines with Oxaloacetate to form Citrate

C Appendix C: Experiment Apparatus

C.1 Lecture slides used in video lecture

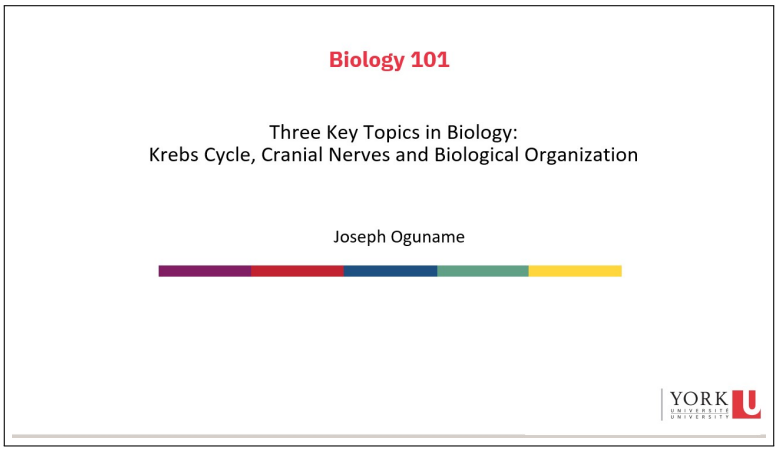

Figure C.1.1: Slide 1. Created by Kiemute Oyibo.

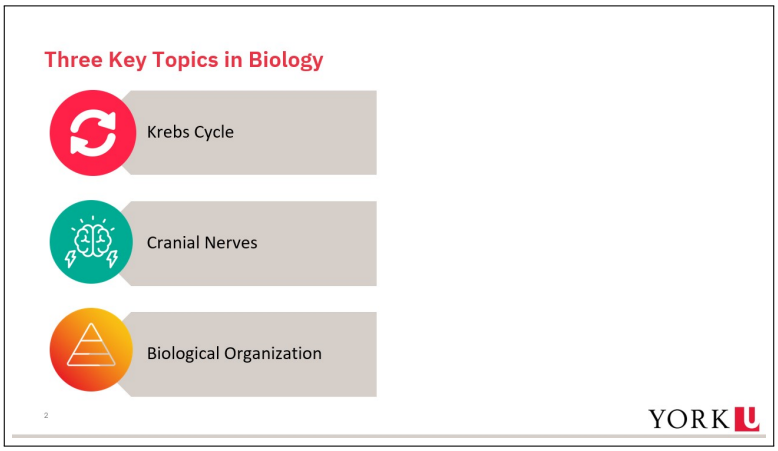

Figure C.1.2: Slide 2. Created by Kiemute Oyibo.

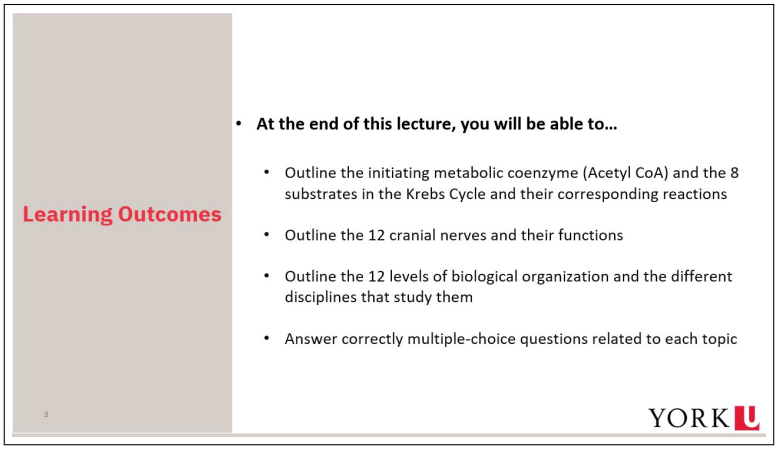

Figure C.1.3: Slide 3. Created by Kiemute Oyibo.

Figure C.1.4: Slide 4. Created by Kiemute Oyibo.

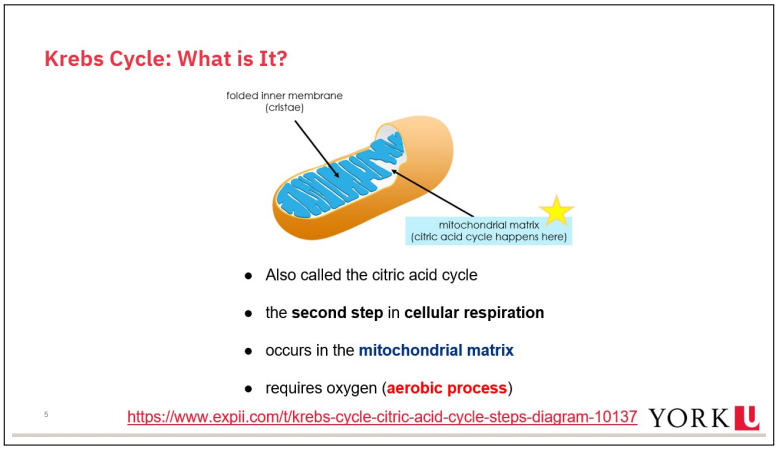

Figure C.1.5: Slide 5. Created by Kiemute Oyibo.

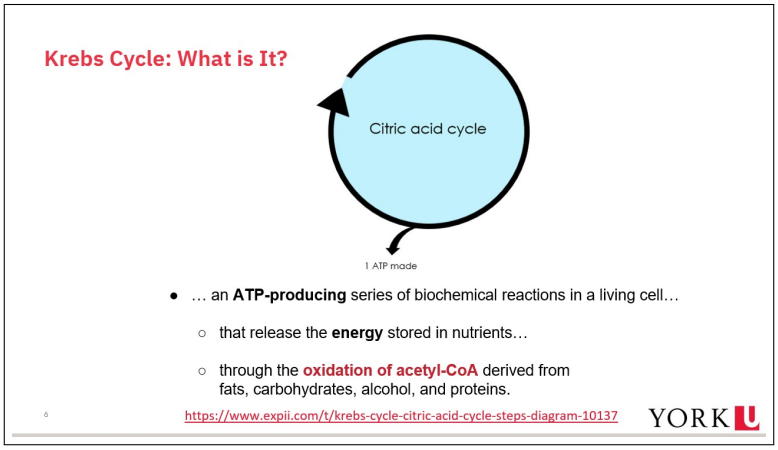

Figure C.1.6: Slide 6. Created by Kiemute Oyibo.

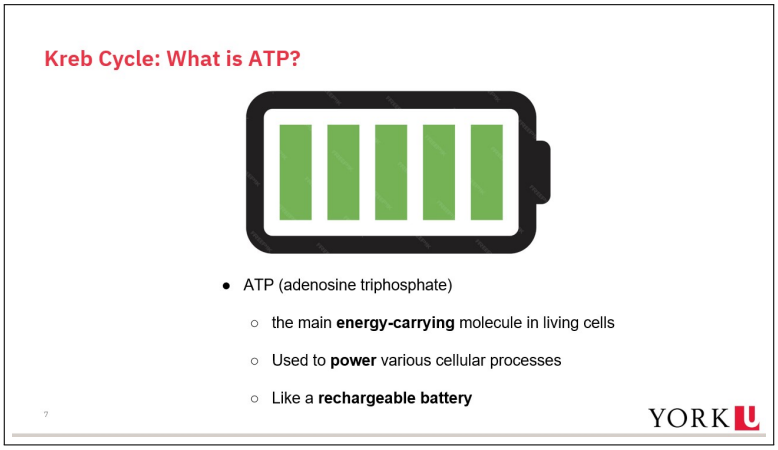

Figure C.1.7: Slide 7. Created by Kiemute Oyibo.

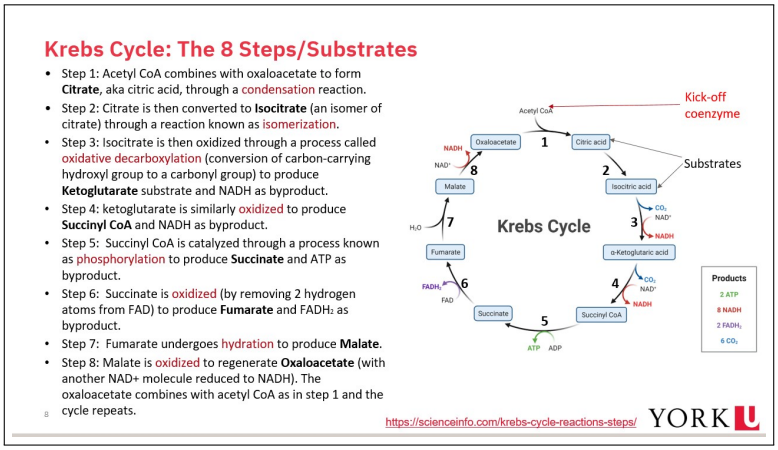

Figure C.1.8: Slide 8. Created by Kiemute Oyibo.

Krebs Cycle: The 8 Reactions

- Step 1: Acetyl CoA combines with oxaloacetate to form **Citrate**, aka citric acid, through a condensation reaction.
- Step 2: Citrate is then converted to **Isocitrate**, an isomer of citrate, through a reaction known as isomerization.
- Step 3: Isocitrate is then oxidized through a process called oxidative decarboxylation (conversion of carbon-carrying hydroxyl group to a carbonyl group) to produce **Ketoglutarate** substrate and NADH as byproduct.
- Step 4: α-ketoglutarate is similarly oxidized to produce **Succinyl CoA** and NADH as byproduct.
- Step 5: Succinyl CoA is catalyzed through a process known as phosphorylation to produce **Succinate** and ATP as byproduct.
- Step 6: Succinate is oxidized (by removing 2 hydrogen atoms from FAD) to produce **Fumarate** and $FADH_2$ as byproduct.
- Step 7: Fumarate undergoes hydration to produce **Malate**.
- Step 8: Malate is oxidized to regenerate **Oxaloacetate** (with another NAD+ molecule reduced to NADH). The oxaloacetate combines with acetyl CoA as in step 1 and the cycle repeats.

*Coenzyme (not a substrate) used to kickstart the series of reactions

Step	Substrate	Reactions
0	Acetyl CoA*	Condensation (Acetyl CoA + oxaloacetate)
1	Citrate	Isomerization
2	Isocitrate	Oxidative decarboxylation (Oxidation)
3	α-Ketoglutarate	Oxidative decarboxylation (Oxidation)
4	Succinyl CoA	Phosphorylation
5	Succinate	Oxidation
6	Fumarate	Hydration
7	Malate	Oxidation
8	Oxaloacetate	

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Figure C.1.9: Slide 9. Created by Kiemute Oyibo.

Cranial Nerves

What It is

12 Nerves

12 Associated functions

10

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Figure C.1.10: Slide 10. Created by Kiemute Oyibo.

The 12 Cranial Nerves and their Functions

- Part of the **peripheral nervous** system
- All 12 nerves originate from the brain except "cranial nerve 11" (Accessory nerve).
- Responsible for transmitting information between
  - the **brain** and
  - various parts of the **head**, **neck**, and **trunk**.
- Play crucial roles in
  - **sensory functions** (vision, hearing, taste, and smell)
  - **motor functions** (facial expressions and tongue movement).
- Each nerve's function (**sensory**, **motor**, or both) shown in the table.

Nerve	Function
Olfactory	Sensory
Optic	Sensory
Oculomotor	Motor
Trochlear	Motor
Trigeminal	Both
Abducens	Motor
Facial	Both
Vestibulocochlear	Sensory
Glossopharyngeal	Both
Vagus	Both
Accessory	Motor
Hypoglossal	Motor

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Figure C.1.11: Slide 11. Created by Kiemute Oyibo.

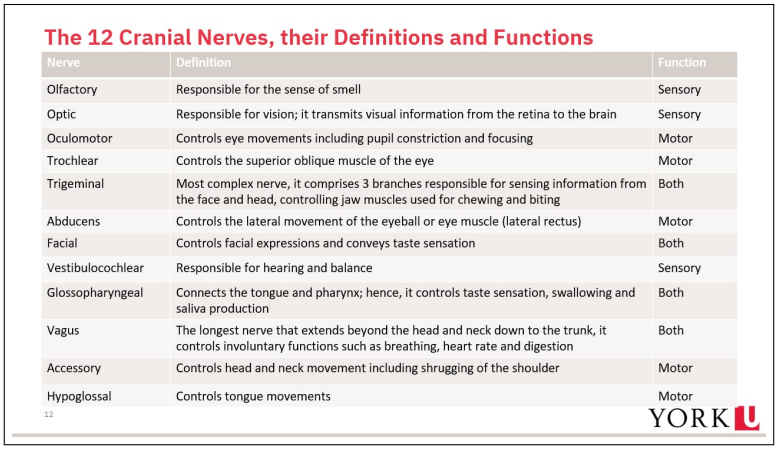

Figure C.1.12: Slide 12. Created by Kiemute Oyibo.

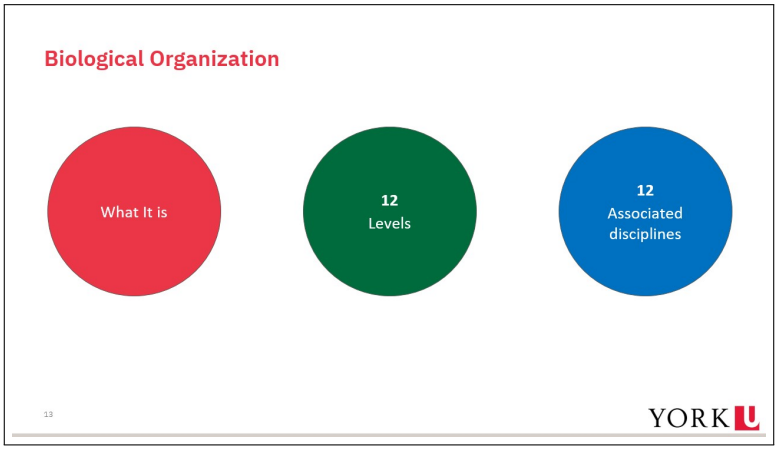

Figure C.1.13: Slide 13. Created by Kiemute Oyibo.

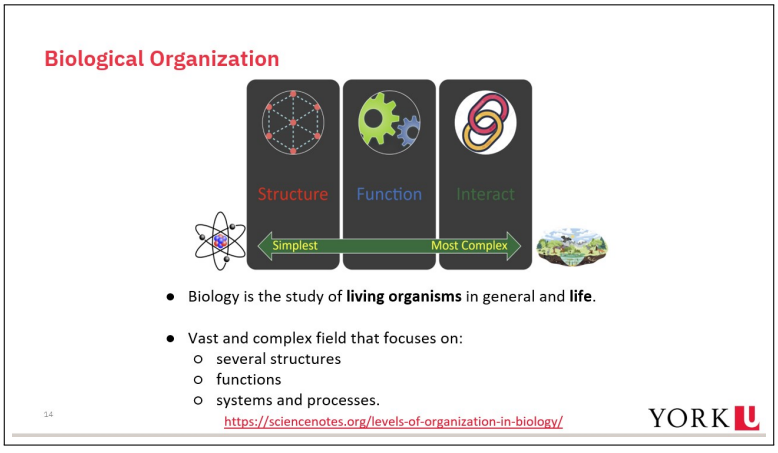

Figure C.1.14: Slide 14. Created by Kiemute Oyibo.

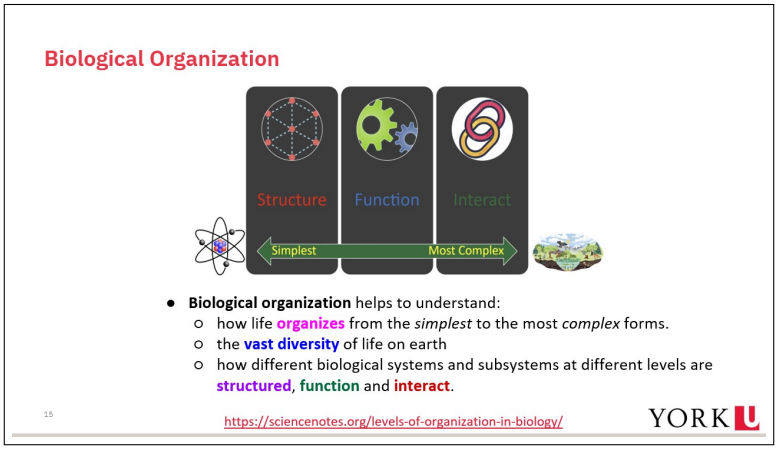

Figure C.1.15: Slide 15. Created by Kiemute Oyibo.

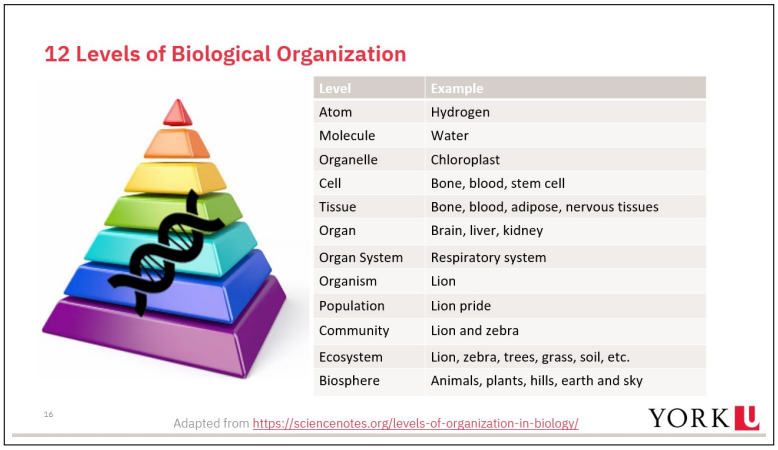

Figure C.1.16: Slide 16. Created by Kiemute Oyibo.

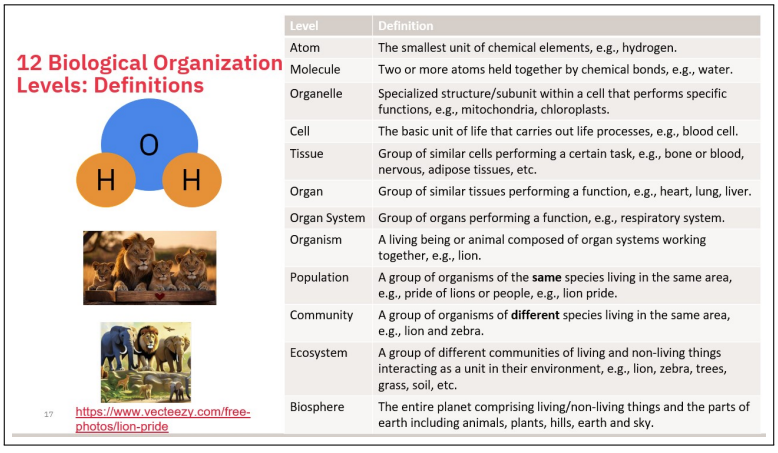

Figure C.1.17: Slide 17. Created by Kiemute Oyibo.

12 Biological Organization Levels: Disciplines

Level	Discipline
Atom	Chemistry
Molecule	Molecular Biology
Organelle	Cellular Biology (Cytology)
Cell	Cellular Biology (Cytology)
Tissue	Histology
Organ	Anatomy
Organ System	Physiology
Organism	Biology
Population	Population Biology
Community	Community Biology
Ecosystem	Ecology
Biosphere	Biogeography

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Figure C.1.18: Slide 18. Created by Kiemute Oyibo.

12 Biological Organization Levels: Disciplines & Definitions

Level	Discipline	Definition
Atom	Chemistry	Studies the properties, composition, and behavior of atoms and how they interact to form molecules
Molecule	Molecular Biology	Examines the molecular mechanisms of biological processes, focusing on the structure and function of molecules such as DNA, RNA, and proteins
Organelle	Cellular Biology (Cytology)	Encompasses the study of cells, including their structures, functions, and organelles
Cell	Cellular Biology (Cytology)	Encompasses the study of cells, including their structures, functions, and organelles
Tissue	Histology	Examines tissues - the groups of similar cells that work together to perform specific functions
Organ	Anatomy	Examines the structure of living organisms, with a particular focus on individual organs
Organ System	Physiology	Investigates the functions of biological systems, including how organ systems operate and interact to sustain life
Organism	Biology	The science of life and living organisms, encompassing various subfields like botany, zoology, and microbiology
Population	Population Biology	The study of how populations of organisms (of the same species) change over time
Community	Community Ecology	Explores the interactions among different species that coexist in the same geographic area
Ecosystem	Ecology	Investigates the relationships between living organisms - including individuals, populations, and communities - and their physical environments
Biosphere	Biogeography	The study of the distribution of species and ecosystems in geographic space and through geological time

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Figure C.1.19: Slide 19. Created by Kiemute Oyibo.

Thank you!

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Figure C.1.20: Slide 20. Created by Kiemute Oyibo.

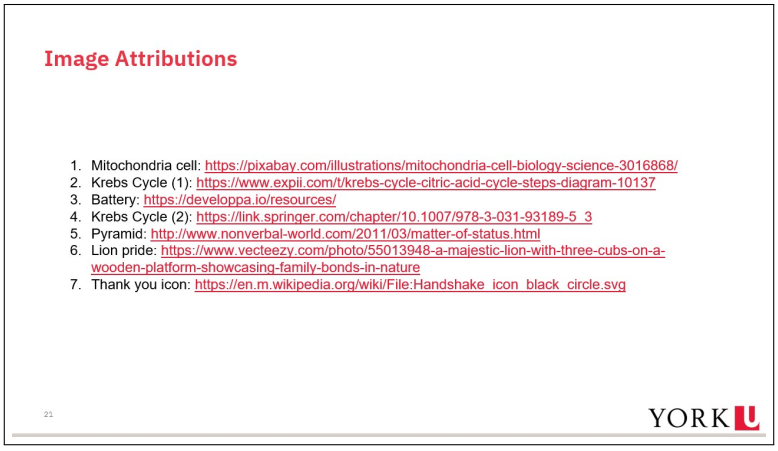


Figure C.1.21: Slide 21. Created by Kiemute Oyibo.

Mnemonics slides provided to Experimental (SAVE) group only

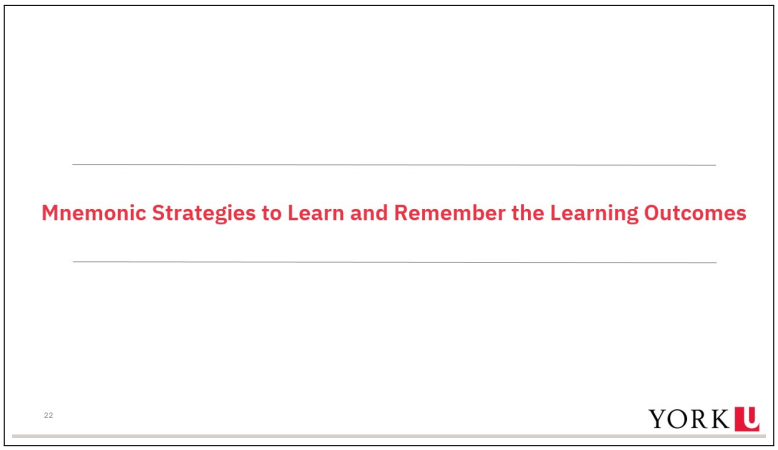


Figure C.1.22: Slide 22. Created by Kiemute Oyibo.

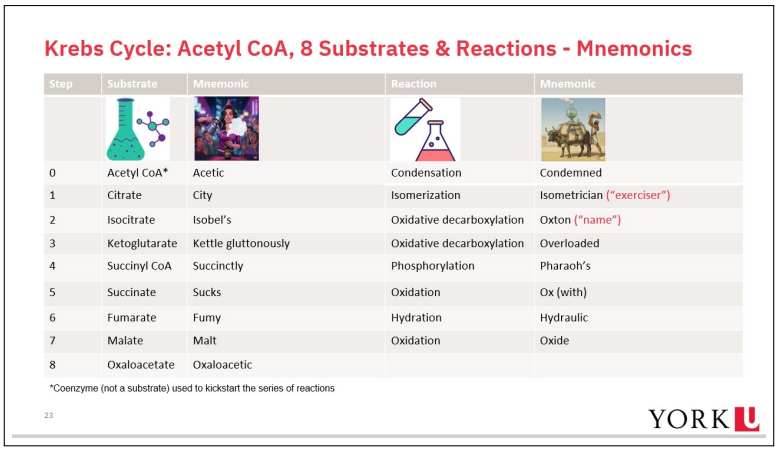


Figure C.1.23: Slide 23. Created by Kiemute Oyibo.

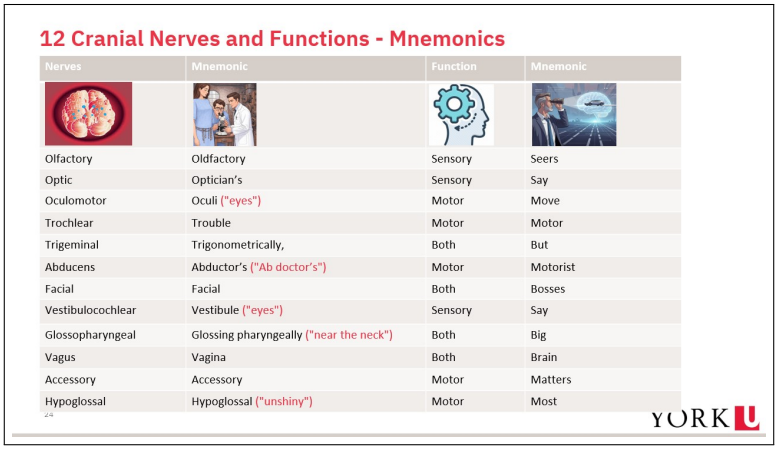


Figure C.1.24: Slide 24. Created by Kiemute Oyibo.

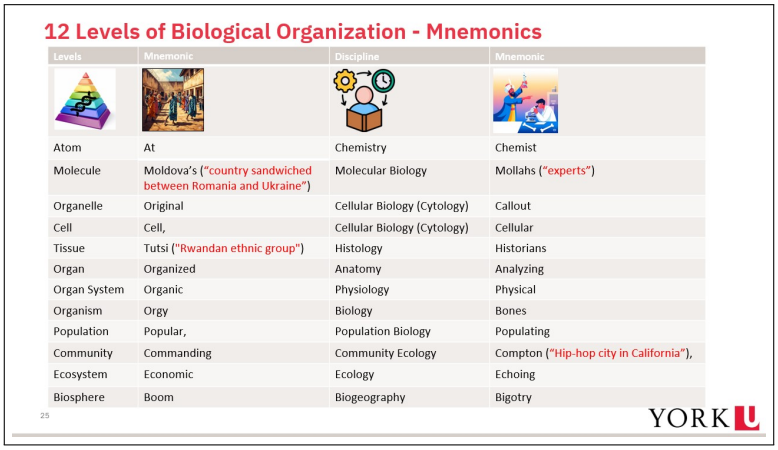


Figure C.1.25: Slide 25. Created by Kiemute Oyibo.

Figure C.1.26: Slide 26. Created by Kiemute Oyibo.

C.2 Mnemonic provided to Experimental group for SAVE Tool training

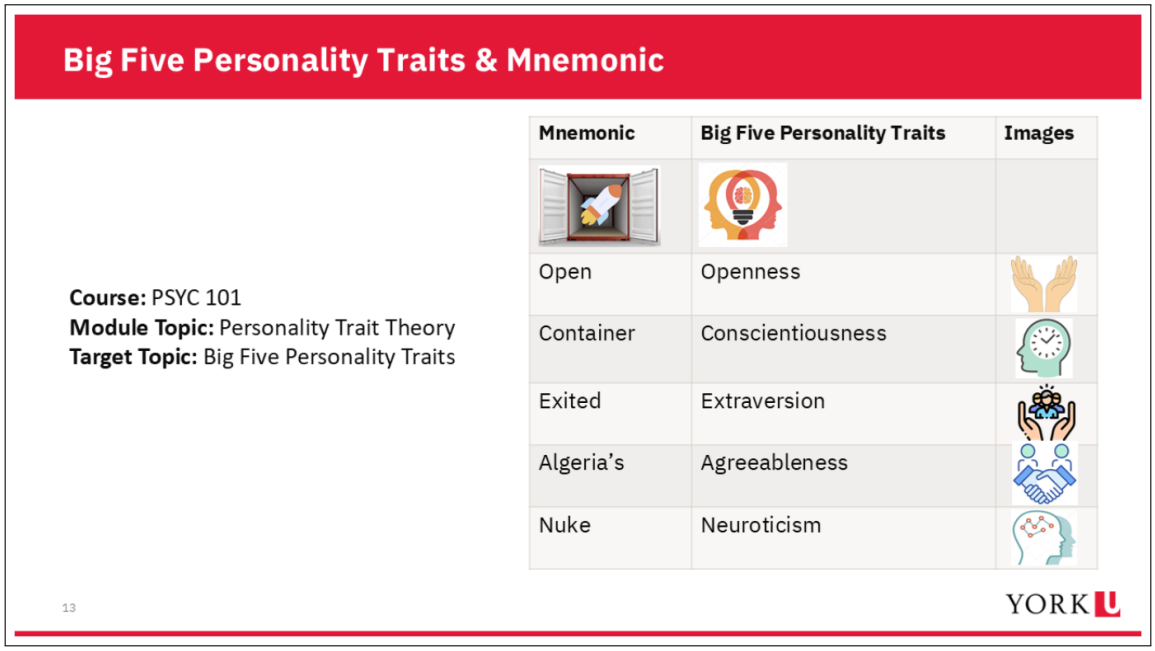
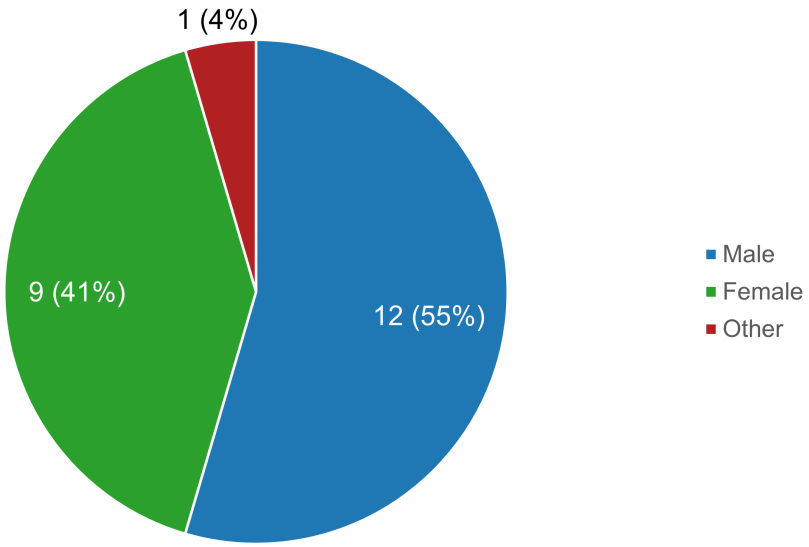


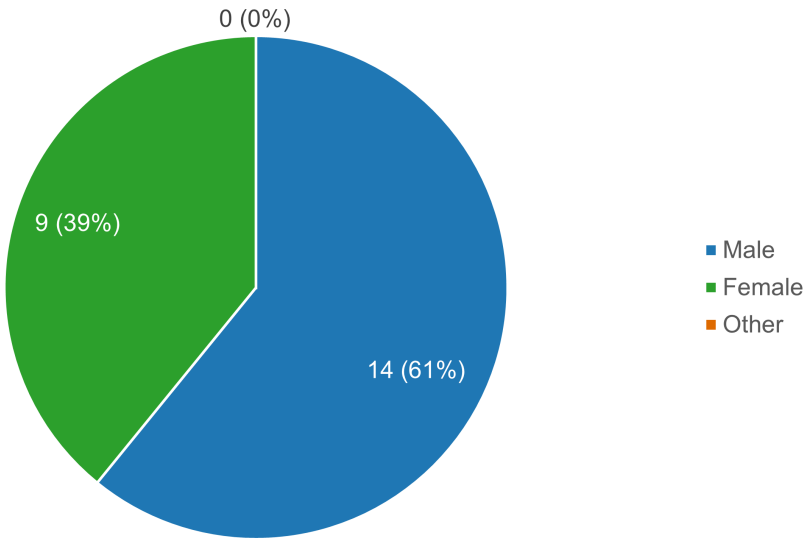
Figure C.2.1: Mnemonic slide for Big Five Personality Traits provided to participants to create using the SAVE Tool [7]. Mnemonic and slide created by Kiemute Oyibo. Images: (1) container image (adapted) [8], (2) nuke image (adapted) [9], (3) brain and mind vector [10], (4) open hands illustration [11], (5) conscientiousness symbol [12], (6) extraversion icon [13], (7) handshake icon [14], and (8) psychology icon [15].

D Appendix D: Participants

D.1 Demographics

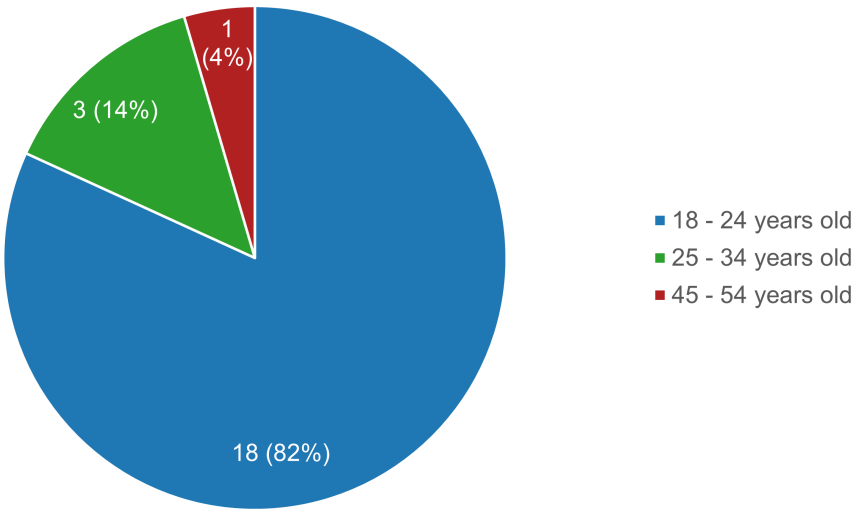


(a) Control group gender demographics

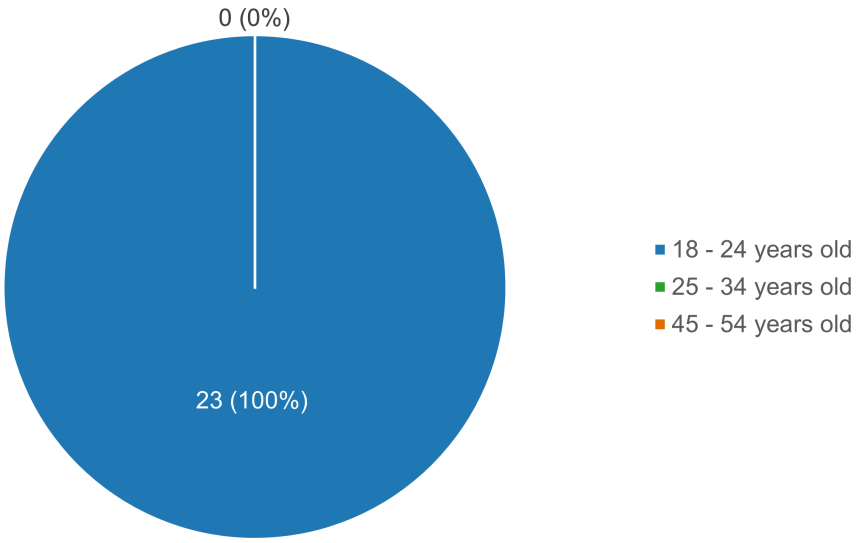


(b) SAVE group gender demographics

Figure D.1.1: Gender demographics of both control and experimental groups. Survey question: *What is your gender?*

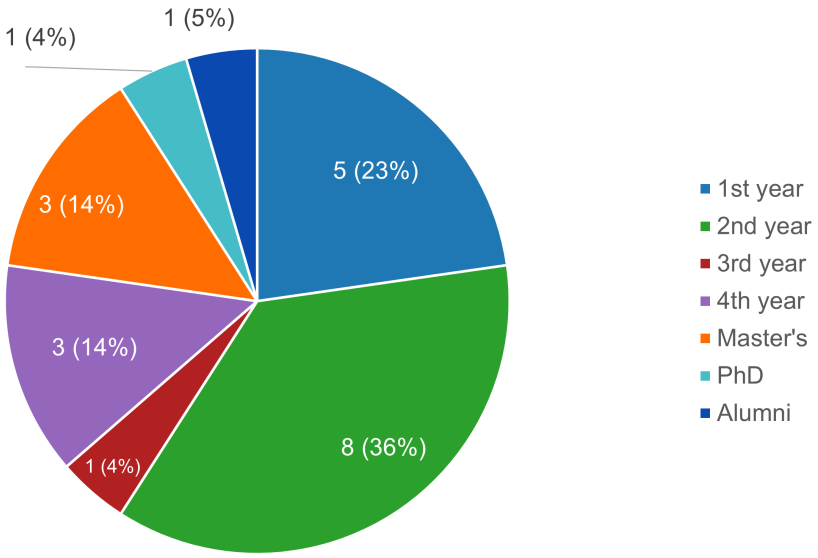


(a) Control group age demographics

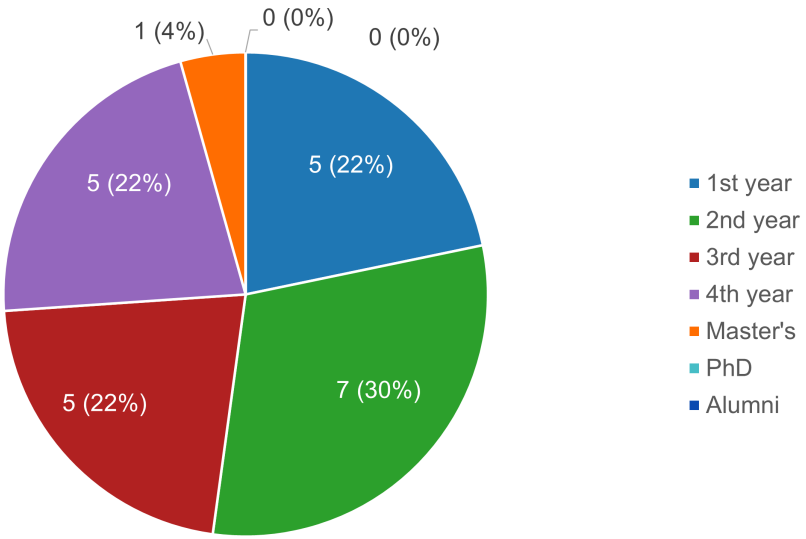


(b) SAVE group age demographics

Figure D.1.2: Age demographics of both control and experimental groups. Survey question: *What is your age?*

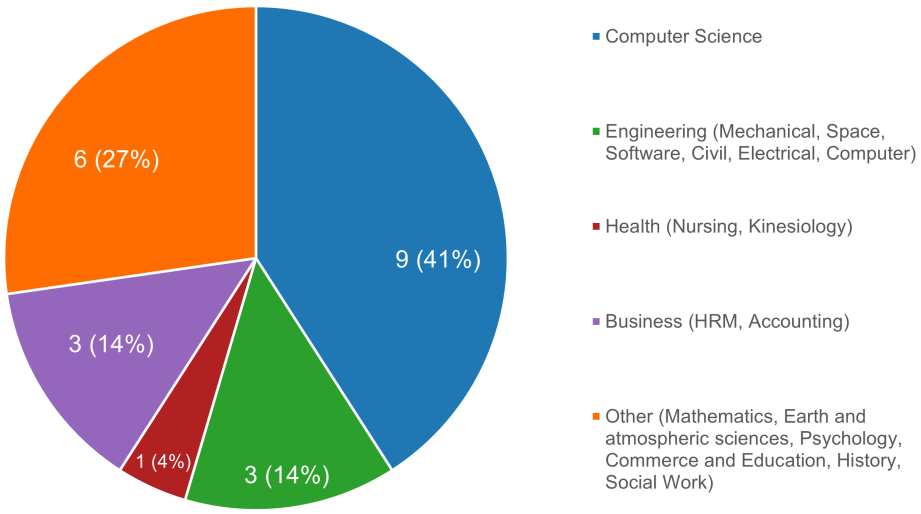


(a) Control group year of study demographics

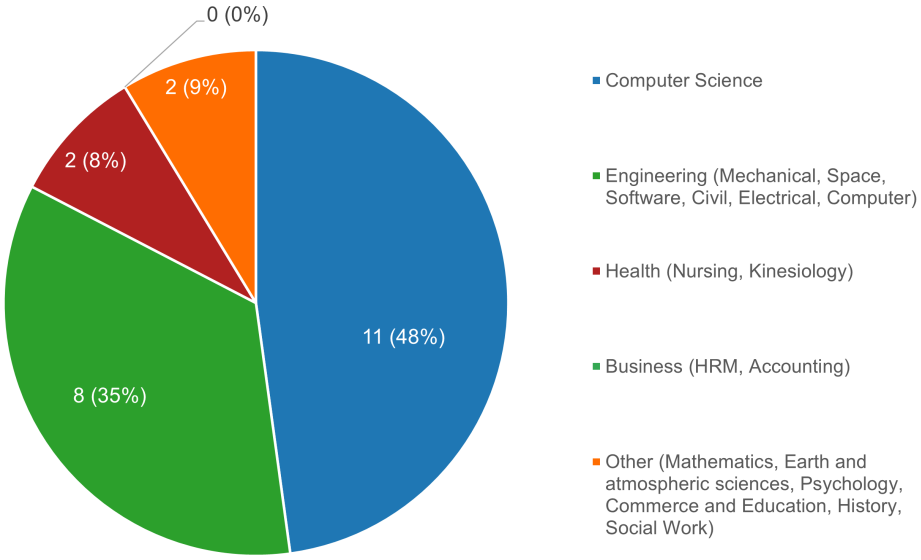


(b) SAVE group year of study demographics

Figure D.1.3: Year of study demographics of both control and experimental groups. Survey question: *What year of study are you in?*

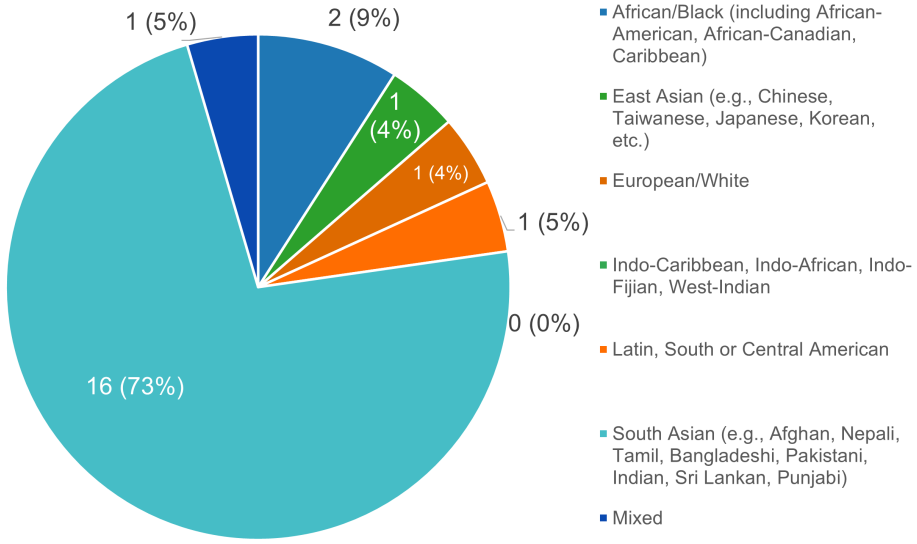


(a) Control group course of study demographics

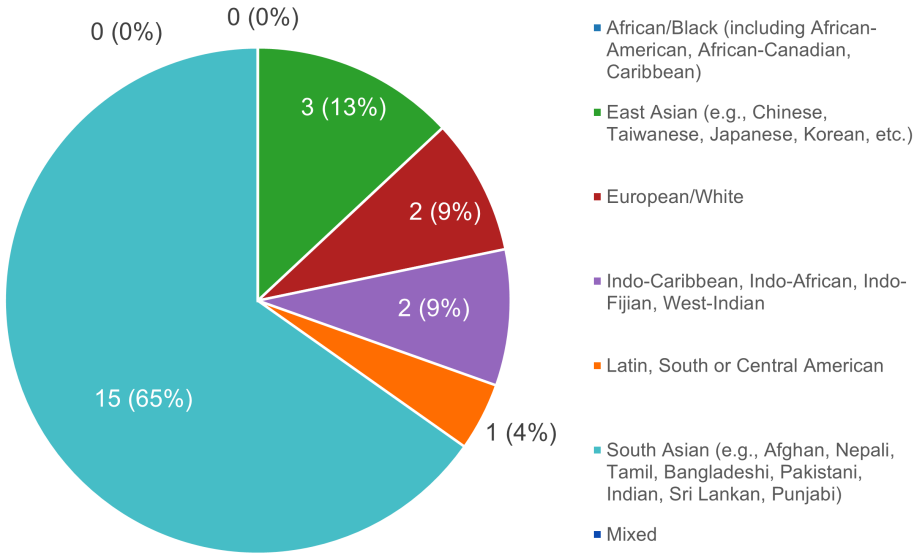


(b) SAVE group course of study demographics

Figure D.1.4: Course of study demographics of both control and experimental groups. Survey question: *What is your course of study?*

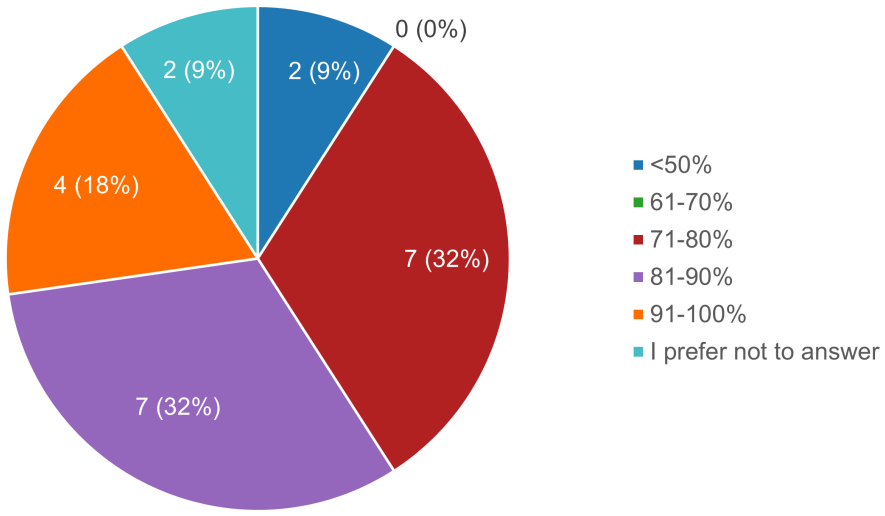


(a) Control group race or ethnicity demographics

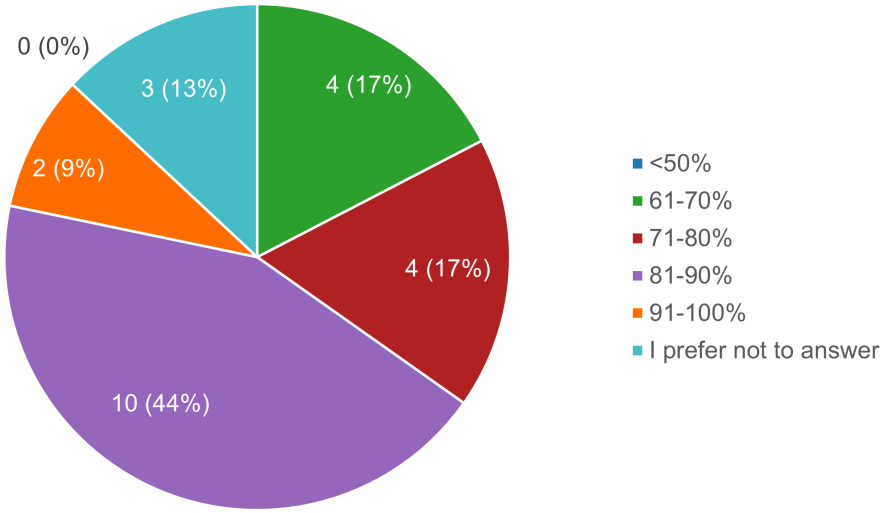


(b) SAVE group race or ethnicity demographics

Figure D.1.5: Race or study demographics of both control and experimental groups. Survey question: *Which race or ethnicity best describes you?*



(a) Control group type of student demographics



(b) SAVE group type of student demographics

Figure D.1.6: Type of student demographics of both control and experimental groups. Survey question: *What type of student do you consider yourself on the average?*

D.2 Participant exclusion based on quiz scores (Participants S21 and S22)

Table D.2.1: Participants S21 and S22 scores for quizzes at times T1, T2, and T3

Participant	**T1 Score**	**T2 Score**	**T3 Score**
Participant S21	0.11	0.03	0.28
Participant S22	0.38	0.20	0.67

E Appendix E: Experiment Results

E.1 Average mean difference for recall and recognition

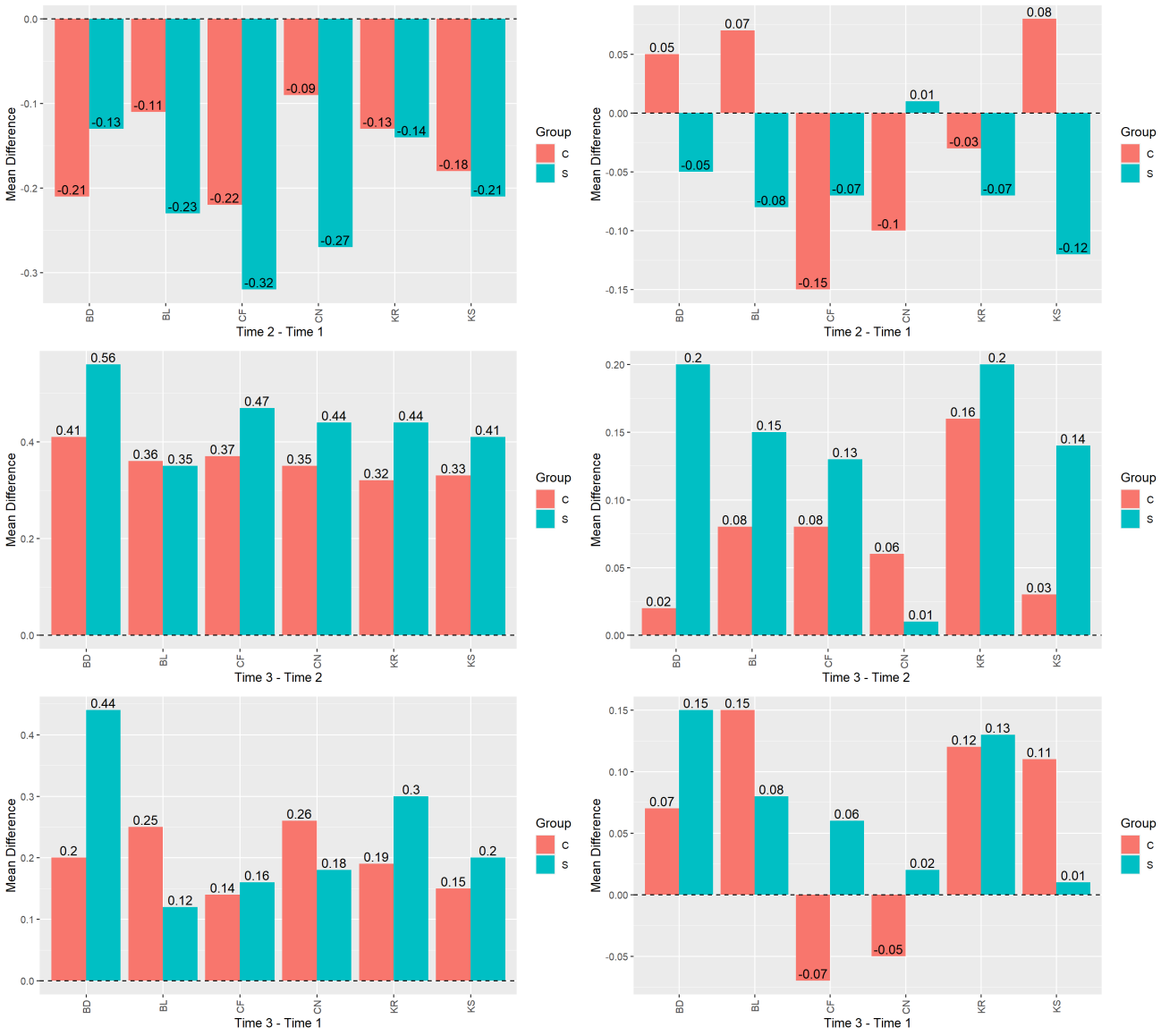


Figure E.1.1: Average mean difference for the recall (remembering - left) and understanding (recognition - right) measures for the specific topics at the three points in time. Group labels: C = Control, S = SAVE. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates.

E.2 Overall four-way RMANOVA – One-way ANOVAs and post-hoc comparisons

Topic-based pairwise comparison

Table E.2.1: Topic-based pairwise comparison with Tukey method family-wise correction. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.62	0.56	75.88	30.90	1505	2.46	0.1382
CN – BL	0.62	0.75	-215.32	30.90	1505	-6.97	0.0000
CN – BD	0.62	0.53	124.05	30.90	1505	4.01	0.0009
CN – KS	0.62	0.48	203.29	30.90	1505	6.58	0.0000
CN – KR	0.62	0.54	258.80	30.90	1505	8.38	0.0000
CF – BL	0.56	0.75	-291.20	30.90	1505	-9.42	0.0000
CF – BD	0.56	0.53	48.17	30.90	1505	1.56	0.6259
CF – KS	0.56	0.48	127.41	30.90	1505	4.12	0.0006
CF – KR	0.56	0.54	182.92	30.90	1505	5.92	0.0000
BL – BD	0.75	0.53	339.37	30.90	1505	10.98	0.0000
BL – KS	0.75	0.48	418.61	30.90	1505	13.55	0.0000
BL – KR	0.75	0.54	474.12	30.90	1505	15.34	0.0000
BD – KS	0.53	0.48	79.24	30.90	1505	2.56	0.1068
BD – KR	0.53	0.54	134.75	30.90	1505	4.36	0.0002
KS – KR	0.48	0.54	55.51	30.90	1505	1.80	0.4683

One-way ANOVA based on condition and time

Table E.2.2: One-way ANOVA based on condition and time due to interaction between them in Table 10 which is not evident or significant at this level of analysis. Condition labels: C = Control, S = SAVE. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of time	T1	0.53	0.58	$F(1, 538) = 2.07$, $p = 0.1507$
	T2	0.45	0.44	$F(1, 538) = 0.09$, $p = 0.768$
	T3	0.66	0.73	$F(1, 538) = 2.46$, $p = 0.1173$
	Time Effect	$F(2, 768) = 32.39$, $p = 0.0000$	$F(2, 803) = 80.42$, $p = 0.0000$	

One-way ANOVA based on condition and task

Table E.2.3: One-way ANOVA based on condition and task due to interaction between them in Table 10 which is not evident or significant at this level of analysis. Tasks: RCL = recall, RCG = recognition. Condition labels: C = Control, S = SAVE.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of task	RCL	0.46	0.52	$F(1, 808) = 6.88$, $p = 0.0089$
	RCG	0.64	0.64	$F(1, 808) = 0.10$, $p = 0.7563$
	Task Effect	$F(1, 769) = 86.25$, $p = 0.0000$	$F(1, 804) = 32.28$, $p = 0.0000$	

One-way ANOVA based on condition and topic

Table E.2.4: One-way ANOVA based on condition and topic due to interaction between them in Table 10. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. Condition labels: C = Control, S = SAVE.

One-way ANOVA at each level of condition				
		C	S	Condition Effect
One-way ANOVA at each level of topic	CN	0.59	0.64	$F(1, 268) = 0.29$, $p = 0.5880$
	CF	0.51	0.62	$F(1, 268) = 8.22$, $p = 0.0045$
	BL	0.75	0.75	$F(1, 268) = 0.45$, $p = 0.5027$
	BD	0.58	0.49	$F(1, 268) = 3.74$, $p = 0.0541$
	KS	0.42	0.54	$F(1, 268) = 7.59$, $p = 0.0063$
	KR	0.44	0.45	$F(1, 268) = 0.03$, $p = 0.8564$
	Topic Effect	$F(5, 765) = 24.13$, $p = 0.0000$	$F(5, 800) = 23.29$, $p = 0.0000$	

Topic-based pairwise comparison for Control group

Table E.2.5: Control group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table E.2.4. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	**Score 1**	**Score 2**	**Estimate**	**SE**	**DF**	***t*.ratio**	***p*-value**
CN – CF	0.59	0.51	62.74	22.58	765	2.78	0.0620
CN – BL	0.59	0.75	-99.27	22.58	765	-4.40	0.0002
CN – BD	0.59	0.58	23.77	22.58	765	1.05	0.8997
CN – KS	0.59	0.42	115.01	22.58	765	5.09	0.0000
CN – KR	0.59	0.44	99.88	22.58	765	4.42	0.0002
CF – BL	0.51	0.75	-162.00	22.58	765	-7.17	0.0000
CF – BD	0.51	0.58	-38.97	22.58	765	-1.73	0.5150
CF – KS	0.51	0.42	52.27	22.58	765	2.32	0.1892
CF – KR	0.51	0.44	37.14	22.58	765	1.65	0.5688
BL – BD	0.75	0.58	123.03	22.58	765	5.45	0.0000
BL – KS	0.75	0.42	214.28	22.58	765	9.49	0.0000
BL – KR	0.75	0.44	199.15	22.58	765	8.82	0.0000
BD – KS	0.58	0.42	91.24	22.58	765	4.04	0.0008
BD – KR	0.58	0.44	76.11	22.58	765	3.37	0.0102
KS – KR	0.42	0.44	-15.13	22.58	765	-0.67	0.9852

Topic-based pairwise comparison for SAVE group

Table E.2.6: SAVE group's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table E.2.4. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.64	0.51	17.13	23.69	800	0.72	0.9791
CN – BL	0.64	0.75	-79.01	23.69	800	-3.34	0.0114
CN – BD	0.64	0.49	109.37	23.69	800	4.62	0.0001
CN – KS	0.64	0.42	83.82	23.69	800	3.54	0.0057
CN – KR	0.64	0.45	139.00	23.69	800	5.87	0.0000
CF – BL	0.51	0.75	-96.14	23.69	800	-4.06	0.0008
CF – BD	0.51	0.49	92.24	23.69	800	3.89	0.0015
CF – KS	0.51	0.42	66.69	23.69	800	2.82	0.0560
CF – KR	0.51	0.45	121.87	23.69	800	5.14	0.0000
BL – BD	0.75	0.49	188.38	23.69	800	7.95	0.0000
BL – KS	0.75	0.42	162.83	23.69	800	6.87	0.0000
BL – KR	0.75	0.45	218.01	23.69	800	9.20	0.0000
BD – KS	0.49	0.42	-25.55	23.69	800	-1.08	0.8899
BD – KR	0.49	0.45	29.63	23.69	800	1.25	0.8115
KS – KR	0.42	0.45	55.18	23.69	800	2.33	0.1834

One-way ANOVA based on task and time

Table E.2.7: One-way ANOVA based on task and time due to interaction between them in Table 10. Tasks: RCL = recall, RCG = recognition. Time labels: T1 = Time 1, T2 = Time 2, T3 = Time 3.

One-way ANOVA at each level of task				
		RCL	RCG	Task Effect
One-way ANOVA at each level of time	T1	0.48	0.63	$F(1, 494) = 41.64$, $p = 0.0000$
	T2	0.30	0.59	$F(1, 494) = 190.40$, $p = 0.0000$
	T3	0.70	0.70	$F(1, 494) = 0.83$, $p = 0.3627$
	Time Effect	$F(2, 763) = 155.77$, $p = 0.0000$	$F(2, 763) = 12.78$, $p = 0.0000$	

Time-based pairwise comparison for recall task

Table E.2.8: Recall task's time-based pairwise comparison with Tukey method familywise correction due to the simple effect of time in Table E.2.7. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
T1 – T2	0.48	0.30	122.51	14.68	763	8.35	0.0000
T1 – T3	0.48	0.70	-136.41	14.68	763	-9.29	0.0000
T2 – T3	0.30	0.70	-258.92	14.68	763	-17.64	0.0000

Time-based pairwise comparison for recognition task

Table E.2.9: Recognition task's time-based pairwise comparison with Tukey method familywise correction due to the simple effect of time in Table E.2.7. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
T1 – T2	0.63	0.59	34.34	16.38	763	2.10	0.0911
T1 – T3	0.63	0.70	-48.08	16.38	763	-2.94	0.0096
T2 – T3	0.59	0.70	-82.42	16.38	763	-5.03	0.0000

One-way ANOVA based on task and topic

Table E.2.10: One-way ANOVA based on task and topic due to interaction between them in Table 10. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. Tasks: RCL = recall, RCG = recognition.

One-way ANOVA at each level of task				
		RCL	RCG	Task Effect
One-way ANOVA at each level of topic	CN	0.42	0.81	$F(1, 224) = 178.42$, $p = 0.0000$
	CF	0.53	0.60	$F(1, 224) = 3.32$, $p = 0.0698$
	BL	0.73	0.77	$F(1, 224) = 3.97$, $p = 0.0475$
	BD	0.48	0.58	$F(1, 224) = 10.85$, $p = 0.0011$
	KS	0.44	0.52	$F(1, 224) = 8.83$, $p = 0.0033$
	KR	0.35	0.55	$F(1, 224) = 42.11$, $p = 0.0000$
	Topic Effect	$F(5, 760) = 31.68$, $p = 0.0000$	$F(5, 760) = 38.14$, $p = 0.0000$	

Topic-based pairwise comparison for recall task

Table E.2.11: Recall task's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table E.2.10. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.42	0.53	-73.90	22.45	760	-3.29	0.0133
CN – BL	0.42	0.73	-206.63	22.45	760	-9.20	0.0000
CN – BD	0.42	0.48	-38.83	22.45	760	-1.73	0.5125
CN – KS	0.42	0.44	-5.57	22.45	760	-0.25	0.9999
CN – KR	0.42	0.35	51.65	22.45	760	2.30	0.1950
CF – BL	0.53	0.73	-132.73	22.45	760	-5.91	0.0000
CF – BD	0.53	0.48	35.07	22.45	760	1.56	0.6238
CF – KS	0.53	0.44	68.33	22.45	760	3.04	0.0291
CF – KR	0.53	0.35	125.55	22.45	760	5.59	0.0000
BL – BD	0.73	0.48	167.80	22.45	760	7.47	0.0000
BL – KS	0.73	0.44	201.06	22.45	760	8.96	0.0000
BL – KR	0.73	0.35	258.28	22.45	760	11.50	0.0000
BD – KS	0.48	0.44	33.26	22.45	760	1.48	0.6763
BD – KR	0.48	0.35	90.48	22.45	760	4.03	0.0000
KS – KR	0.44	0.35	57.22	22.45	760	2.55	0.1116

Topic-based pairwise comparison for recognition task

Table E.2.12: Recognition task's topic-based pairwise comparison with Tukey method familywise correction due to the simple effect of topic in Table E.2.10. Topic labels: BL = Biological Organization Levels, BD = Biological Organization Disciplines, CF = Cranial Nerve Functions, CN = Cranial Nerves, KR = Krebs Cycle Reactions, KS = Krebs Cycle Substrates. DF = degrees of freedom.

Contrast	Score 1	Score 2	Estimate	SE	DF	*t*.ratio	*p*-value
CN – CF	0.81	0.60	164.77	21.09	760	7.81	0.0000
CN – BL	0.81	0.77	34.30	21.09	760	1.63	0.5814
CN – BD	0.81	0.58	175.84	21.09	760	8.34	0.0000
CN – KS	0.81	0.52	217.63	21.09	760	10.32	0.0000
CN – KR	0.81	0.55	203.61	21.09	760	9.65	0.0000
CF – BL	0.60	0.77	-130.47	21.09	760	-6.19	0.0000
CF – BD	0.60	0.58	11.07	21.09	760	0.52	0.9952
CF – KS	0.60	0.52	52.85	21.09	760	2.51	0.1237
CF – KR	0.60	0.55	38.84	21.09	760	1.84	0.4397
BL – BD	0.77	0.58	141.54	21.09	760	6.71	0.0000
BL – KS	0.77	0.52	183.33	21.09	760	8.69	0.0000
BL – KR	0.77	0.55	169.31	21.09	760	8.03	0.0000
BD – KS	0.58	0.52	41.79	21.09	760	1.98	0.3542
BD – KR	0.58	0.55	27.77	21.09	760	1.32	0.7758
KS – KR	0.52	0.55	-14.01	21.09	760	-0.66	0.9857