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Conceptual understanding and student attitudes towards the use of digital flashcards

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ABSTRACT

This study aims to determine how the use of flashcards in an online environment can influence motivation for revising and the achievement of conceptual understanding of biological content. The sample consisted of fifth-grade students (N=112), of whom 59 used online interactive flashcards created with the CRAM system. A control group of 53 students revised the same educational topics using traditional methods through discussion. After the revision, students took a final assessment. A survey questionnaire was used to gather information on the learning experience with flashcards, in which students evaluated their experiences and shared their impressions. A comparison of the final assessment results reveals that students who revised using flashcards performed better on tasks assessing knowledge reproduction and higher-order cognitive tasks than students who revised through discussion. Most students assessed that learning with online flashcards was more practical and easier than traditional revision through discussion, and those who used hint cards found them helpful for a better understanding of biological content. Flashcards have proven to be an effective method for revising biology content. In addition to memorizing, flashcards also enable better understanding with good visual support for conceptual understanding, whereby students show positive attitudes towards this learning approach.

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1. INTRODUCTION

As technology and lifestyle evolve, learning, teaching, and revision methods are also rapidly changing. Students of younger generations belong to the Alpha generation, a cohort exposed to technology and information, who travel from an early age and spend most of their free time in front of screens [1]. Alpha-generation students often choose dynamic forms of learning that help them maintain focus and independently select their path to acquire knowledge, including the topics they will study and the methods to develop competencies and skills [2]. Due to rapid technological changes, education must adapt to trends that influence learning, as technological innovations will gradually transform how educational institutions teach and how students learn [3].

The study by Wulandari [4] demonstrated that 5th grade students often use flashcards for learning and revision before exams. These flashcards typically have the term on one side and its explanation on the other. Wulandari [4] concluded that the flashcard learning method have significantly increased students' knowledge, and thus the interest in this method of learning and repetition is much greater. It is highly likely that the use of

flashcards for learning will become increasingly common on computers, tablets, and smartphones in the coming years [4].

Today, flashcards are also available in digital form. Digital flashcards offer several advantages over traditional ones, such as greater control over progress during learning with easy analysis of accuracy frequency on specific cards, straightforward elimination of certain cards for subsequent learning phases, the ability to use various tools for different methods of using flashcards (e.g., quizzes and matching), and much more [5]. The popularity of card-based learning applications is steadily increasing these days, and the number of different applications is on the rise [6]. For example, one of the most well-known applications, Quizlet, used by over 2/3 of high school students, and 1/2 of college students [7] and continuously expands with new tools and features. Similarly, the CRAM application has over 3 million active users and over 195 million created flashcards [8]. A key advantage of CRAM is that it facilitates the easy creation of online flashcards and promotes self-regulated learning in its basic form, as further review and learning success are based on the student's decisions. Specifically, when using flashcards, students can mark terms they have not yet mastered and eliminate those they have already learned. It allows for greater focus on unfamiliar terms, leading to more frequent repetition and faster memorization [5]. The ability to eliminate terms that students believe they have already mastered influences self-regulation in learning, during which the student has complete control over their learning process. This includes planning learning activities, deciding whether to extend the learning process and assessing the effectiveness of such activities on their knowledge [9]. In paper-based flashcards, students should discard cards they have already memorized and those they find challenging to learn in the initial rounds of study. Subsequently, in later rounds, they should gradually reintroduce and focus on the content they struggle to memorize and comprehend [10]. Through mobile applications (e.g., CRAM), all flashcards are reviewed in the first round, while in subsequent rounds, only those cards marked as "not learned" are retained. This approach improves focus on less well-mastered material and facilitates self-monitoring during the learning process [10].

Xodabande *et al.* [10] found that students who utilized physical flashcards for revision across five months sessions achieved significantly lower results than those who did use digital flashcards on smartphones. Similarly, Zakian *et al.* [11] demonstrated that using mobile devices and applications for vocabulary learning significantly contributes to accelerated vocabulary development with long-term effects. In the field of biology, recent studies conducted on medical [12], [13], and biology [14] students indicate that the use of flashcards reduces pre-exam anxiety, enhances motivation for learning, and consequently improves learning outcomes. College students already possess established learning techniques that suit their needs and pre-existing attitudes toward specific topics and methods for interpreting them after learning [15]. Therefore, they cannot be directly compared or equated with primary school students, which is one of the main reasons for conducting this research.

The effectiveness of active learning is best understood through Bloom's taxonomy [16]. This taxonomy serves as a framework that aids educators in classifying statements used to predict students' skills [17]. Research has shown that flashcards have a positive effect on reproducing knowledge [12], [13], but the question arises whether it can also affect higher cognitive levels (CLs)? The CLs of knowledge a student acquires can be determined using Crooks's [18] adaptation of Bloom's taxonomy, which differentiates between reproductive knowledge, understanding and application, and problem-solving [19]. Reproduction, as the first level, according to Crooks, involves memorization of data with a literal understanding, which does not necessarily imply comprehension of the underlying concept. The second level encompasses a conceptual understanding of the educational content, while the third level integrates higher CLs of Bloom's taxonomy (analysis, evaluation, and creation) [19]. According to constructivist theory, conceptual understanding connects prior knowledge with new information [20]. To enhance learning, students should analyze new information through conceptual change [20]. Recent studies indicate that digital technology positively affects conceptual understanding and motivation [21], [22]. However, there is a lack of research on the impact of digital flashcards on conceptual understanding in biology education.

In the context of learning with digital tools, the impact of guidance on student achievement can be compared. Wankiiri-Hale *et al.* [23] have proven that even students find it much easier to learn if they have some form of guidance through the learning process. Doukakis *et al.* [24] conclude that tutored approach guidance (which provides carefully designed intelligent hints or feedback during system interactions) in digital tools gives students the opportunity to improve their level of knowledge, skills and attitudes towards any discipline and technology at any time and regardless of distance. The CRAM application, in addition to enabling easy creation of online flashcards, also provides support to students in the form of hint cards. Hint cards further motivate students to reflect on concepts they could not initially identify from the first prompt, facilitating the tutored approach. These cards do not reveal the central concept directly but guide students toward it, thus sparking their curiosity [25]. It has been shown that the tutored approach also positively impacts digital flashcards, especially when improving vocabulary use in context of sentences [26], allowing students

to develop their imaginations without the limitations that come with strict guidance but also construct explanations, which is necessary to achieve conceptual understanding. One of the objectives of this study is to examine the impact of the tutored approach, specifically the use of hint cards, on students' knowledge of biological concepts.

The study by Zung *et al.* [9], demonstrated that learning with the help of digital flashcards significantly increases students' motivation yet relatively little is known about why and how students actually use digital flashcards during self-regulated learning, and whether such uses are supported by research from the science of learning. Even though students are mostly motivated to learn with flashcards and students will choose this method of repetition in most cases, it has not yet been studied at what CL students use flashcards. From the above facts, Zung *et al.* [9] conclude that more pedagogically based research is needed to examine not only motivation but also the quality of learning with flashcards.

Younger generations are characterized by their use of diverse learning resources, with the Internet being one of the most significant. Therefore, it is essential to prepare students for proper Internet use and provide high-quality online learning materials [27]. Assessing knowledge through educational games offers unique experiences, gathers extensive learning data, and provides student's real-time feedback. Consequently, learning through online educational games is both inspiring and promising [28]. Digital flashcards are one of the newer, interactive online learning resources with game elements. However, their use in biology at the elementary school level has not been sufficiently explored. Similarly, previous studies have primarily used flashcards to examine learning outcomes related to vocabulary acquisition [26] or the recall of complex technical terms [11], [12]. In contrast, this research will also assess achievements at higher CLs.

This study aims to investigate the effect of learning with digital flashcards on students' knowledge in biology, with an additional goal of assessing students' opinions on using such cards for learning. In line with these objectives, the following hypotheses have been proposed:

- H1: students who used digital flashcards for learning will achieve better success on the final assessment compared to those who revised through the traditional method of classroom discussions.
- H2: students who used digital flashcards for learning will be more successful in solving tasks requiring higher CLs than those who revised through the traditional method of classroom discussions.
- H3: students have a positive opinion regarding flashcards' practicality and ease of use.
- H4: students who used hint cards during their learning process find them helpful for better understanding.

2. METHOD

The study involved fifth-grade students from six elementary schools, with three schools forming the experimental group (E) and three schools forming the control group (C). The sample consisted of 112 students (N=112) who completed an identical final assessment online. The experimental group (E) revised using flashcards (N_E=59), while the control group (N_C=53) revised in a traditional manner (through discussion) without using flashcards. The research was conducted during the 2022/2023 school year.

Teachers (N_{UE}=3; N_{UC}=3) used the same materials on the BUBO platform, developed as part of the "Teaching biology in an epidemiologically adapted research environment" project. The project's main goal was to create a platform tailored for teaching and learning biology in online and hybrid formats according to the national curriculum for biology education. The BUBO platform was designed for biology instruction both in the classroom and at home. It includes materials and employs various tools for learning and revising biological content, focusing on concepts such as: the energy impacts of nutrition on living organisms, adaptations of living organisms as a result of evolution, and simulation of field research. All materials, created by different teams of teachers and experts from higher education institutions, were reviewed and organized into age-appropriate e-courses to enable students' easier use.

Students in the experimental group revised the instructional content using flashcards multiple times, specifically until they could recognize all terms on the first attempt of each transition. In contrast, students in the control group revised through discussions with the teacher. The flashcards used in this study featured a riddle on the front that guided students toward the term, which was revealed by flipping the card. The flashcards were created in the CRAM system, which allows students to indicate whether they knew the statement after each card (leitner system). In subsequent rounds of revision, only the statements the student did not know in the previous round appeared [8]. Students revised using three sets of cards aligned with the outcomes of the national curriculum for 11-year-olds: "What properties does water have?", "From the sun to the plate", and "Living and surviving in water". Hint cards were provided as part of the tutored approach for each question to lead students to correct answers if needed. These hints primarily involved visualizations that supported the conceptual understanding needed to answer the primary cards, as shown in Figure 1.

The research instruments used in this study were: the knowledge assessment results and a questionnaire through which students evaluated their experiences and provided feedback on learning with flashcards. Students completed an online final knowledge assessment that tested the outcomes taught using

materials and reviewed with flashcards. The final assessment team did not create flashcards for content review, but the reviewers were the same. The final assessment was deemed acceptable (α=0.625) according to Raharjanti *et al.* [29] and it contained three series of tasks (in addition to two researched concepts and a field research simulation) with three particles each. It was designed to evaluate three CLls [18]: I. (reproductive knowledge), II. (understanding and application), and III. (problem-solving). In each series of tasks, the 1st task checked reproductive knowledge (I. CL), the 2nd task checked understanding and application of knowledge (II. CL), and the 3rd task checked problem solving (III. CL). The particles were structured as two-part tasks [30], where the first part (a) was a multiple-choice question, and the second part (b) was an open-ended question requiring an explanation of the answer to the closed part. All answers were coded for metric analysis at a true-false level. At the same time, specific biological meaning coding was applied to questions directly related to the biological content presented on the flashcards. This specific biological meaning coding was used to determine additional connections between the impact of flashcards and student success in answering open-ended questions, aiming to understand what each student's response signifies for their comprehension of a particular biological concept. Students' answers from each task of the final assessment were entered into Microsoft Excel (version 2210), and the sample was categorized into classes of performance based on the percentage of success in completing the assessment. Each class included data corresponding to 10% intervals of student success in the final assessment (class: 10%=0-10%, 20%=11%-20%, …, 90%=81%- 90%, 100%=91%-100%).

The non-standardized questionnaire prepared for this study contained ten statements that assessed students' opinions about their experience with learning using flashcards, with responses on a three-point Likert scale (strongly disagree, somewhat agree, agree). A three-point scale was used due to the younger age of the respondents (11 and 12 years). It also included two multiple-choice questions regarding the number of card transitions and four open-ended questions related to specific learning experiences. The data collected from the questionnaire did not significantly deviate when comparing respondents (α=0.618), according to Raharjanti *et al.* [29]. For the descriptive statistics of the final assessment results, the arithmetic mean was used as a measure of central tendency, and the standard deviation served as a measure of dispersion. The distribution of the final assessment and questionnaire results was tested using the Kolmogorov-Smirnov test and presented with skewness and kurtosis measures. The Mann-Whitney U test was used to examine differences in final assessment performance, compare the success of solving each task individually, and assess task performance across CLs between the control and experimental groups. The results from the questionnaire regarding students' attitudes were graphically presented according to the number of students and performance class, and Spearman's rank correlation was used to determine correlations between questions and performance classes [31]. All results were analyzed using the SPSS 22 software package (IBM, 2013).

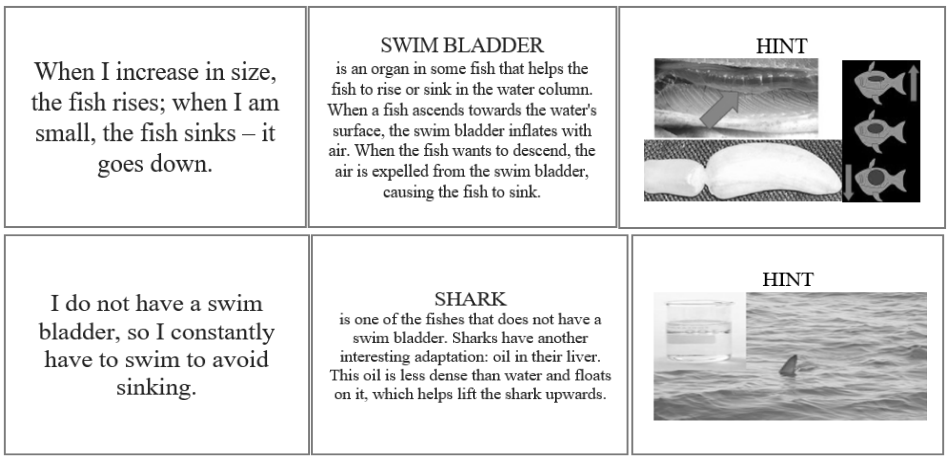


Figure 1. Two examples of flashcards with all three segments-riddle, explanation and hint card

3. RESULTS AND DISCUSSION

The arithmetic mean was used to measure the central tendency for the assessment results (M=9.179). The standard deviation (SD=15.58) was used as a measure of dispersion. The data distribution is positively skewed, indicating more extreme results with higher values. The sample includes results that deviate from the mean and exhibit substantial dispersion (κ<3), leading to a platykurtic distribution (skewness=5.234/0.228,

kurtosis=28.451/0.453). The Kolmogorov-Smirnov test indicates that the final assessment data and the data from all questionnaire items are not normally distributed ($p<0.05$).

3.1. Results of the final knowledge assessment

The range of performance classes in the final knowledge assessment, from 10% to 80% correct answers, indicates that no students achieved over 90% accuracy, as shown in Figure 2. According to the performance classes, the highest number of students (41.38%) scored between 20% and 30% (with specific percentages being 21.20% and 20.18%, respectively). Only 4.59% of students achieved up to 70%, and 2.75% achieved up to 80% accuracy. The mean score of the final assessment was relatively low (M=37.83±21.25), and the distribution exhibited positive skewness with a rightward tilt. The specific conditions of online learning, which students and teachers were unaccustomed to before the pandemic, likely contributed to the generally lower performance levels observed in the knowledge assessment. Despite this, the average performance of 38% is consistent with the 40% average achievement for biology assessments at the national level. With the introduction of new generations of students and increased use of ICT in education, the impact of flashcards on student success is expected to improve. Nadeak [32], concluded that for parents satisfied with a child's success, their learning and independent work during lessons are paramount. Online flashcards can provide such support, facilitating independent learning opportunities for students.

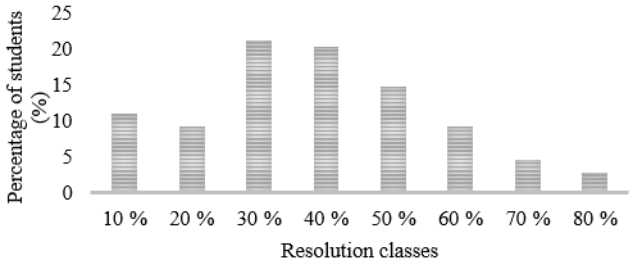


Figure 2. Overall average percentage performance on the final assessment by resolution classes

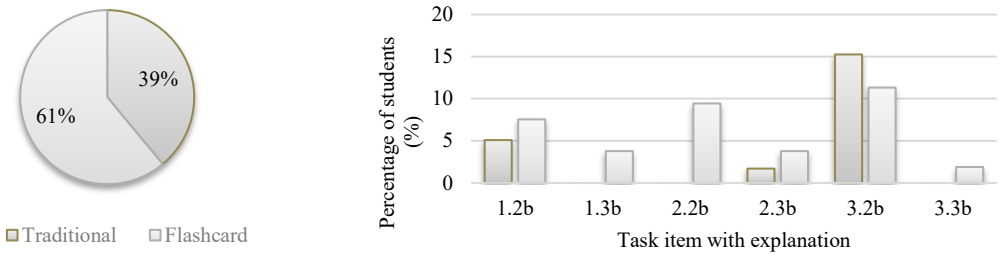
The Mann-Whitney U test was used to compare the data on the completion of the final assessment between the experimental and control groups. However, no statistically significant difference was found, which refutes the hypothesis that students in the experimental group would achieve better results on the final assessment than those in the control group. However, when comparing the mean values of completion across CLs as shown in Table 1, it was observed that the mean ranks in all CLs were slightly higher compared to the control group, indicating that flashcards facilitated effective learning. For knowledge reproduction (I. CL) and problem-solving (III. CL), a statistically significant difference was found in favor of students who used flashcards (Table 1). Xodabande *et al.* [5] and Azizah *et al.* [33] also concluded that flashcards are beneficial for knowledge reproduction, as their studies confirmed that flashcards aid in memorizing terms and brief definitions, thus enabling the successful completion of reproductive tasks. Previous research on biology has shown that flashcards help reproduce biological content that requires learning entirely new and complex terms [11], [12] and additionally, in this research it was shown that the positive part is also at higher CLs.

This research, along with each CL, also examined the explanation of the answers in the second layer of questions, which was intended to check the student's understanding of the answer to a closed part of the question. Two-tier tasks are effective in assessing conceptual understanding [34]. They can also be used as an alternative for evaluating student learning outcomes due to the second part of the task, which tests comprehension [33]. Although only a small number of students completed the task items requiring explanations, in three task items, correct answers were provided exclusively by students who used flashcards for learning and the differences in the performance of explanations can be seen in Figure 3. Additionally, students in the experimental group demonstrated a 22% difference in explaining most tasks, as illustrated in Figure 3(a). When comparing tasks at higher CLs, specifically, tasks 2 and 3 in each set of tasks, the experimental group is also better at performing, indicating a better trend in understanding the content as shown in Figure 3(b). It is also noted that for some tasks (3 out of 6), only students who learned using flashcards provided explanations for answers at higher CLs and in two additional tasks, they outperformed students in the control group as shown in Figure 3(b). These results are consistent with the findings of Nasution and Tambunan [35], which indicate a relationship between motivation, cognitive engagement, and conceptual change. This study demonstrates that students who use flashcards are more successful at explaining their

answers to higher-order cognitive tasks, which require a greater cognitive engagement level and motivation to learn, compared to students who apply traditional review methods.

Table 1. Comparison of final assessment completion data between experimental and control groups across CLs

	Revising method	Mean rank	Mann-Whitney U	p
I. CL	Flashcards	64.40	1097.50	0.006
	Conversation	47.71		
II. CL	Flashcards	58.36	1453.50	0.092
	Conversation	54.42		
III. CL	Flashcards	61.85	1248.00	0.049
	Conversation	50.55		



(a) (b)

Figure 3. Differences in student explanations during conceptual understanding and problem-solving tasks for the traditional revision (control group) and the flashcards revision (experimental group): (a) the overall comparison and (b) the item-by-item comparison across explanatory task items (question part b), where the conceptual understanding second task in the series and problem-solving third task in the series

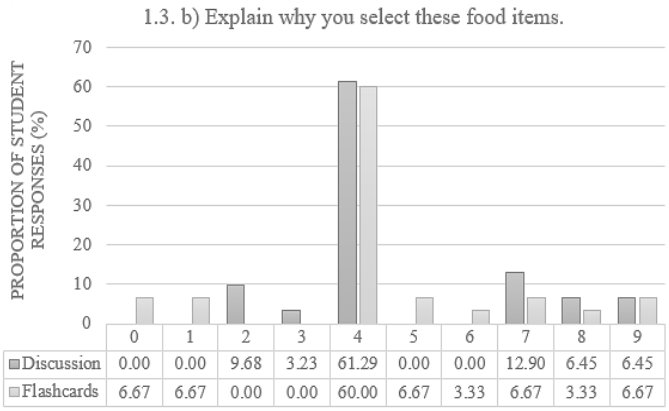
When comparing the resolution of individual items based on the mean ranks from the Mann-Whitney U test, a statistically significant difference was found in five items favoring the experimental group as shown in Table 2, indicating that these items were well-supported by flashcards. Specifically, four out of five items, which represent the second (b) part of the task—i.e., the explanation of the answers to the closed part of the item—were more effectively addressed by students in the experimental group. In a similar study using two-tier tasks to assess understanding of biotechnology concepts, Rukayah *et al.* [34] concluded that the chosen method benefits teachers in evaluating similar concepts. This result is also supported by the specific coding of biological meaning in students' responses, as detailed in the descriptions of the results for these items. This confirms the hypothesis that students in the experimental group are more successful in solving higher-order cognitive tasks compared to students in the control group.

Table 2. Results of the Mann-Whitney U test for comparing knowledge between the experimental (E) and control (C) groups by individual question items

Task	1.1.a	1.3.b	2.2.b	2.3.b	3.3.b
Mean ranks (E)	55.46	53.05	55.87	51.41	50.22
Mean ranks (C)	43.18	45.34	42.00	44.93	46.00
U	876	986.5	816.0	971.5	1025.0
p	0.003	0.014	0.000	0.018	0.032

One example of improved content understanding is demonstrated in the task 1.3.b, where students are required to justify their choice of breakfast foods as shown in Figure 4. If the responses of students in the experimental and control groups are compared by encoding all answers using the ten basic codes (ranging from 0 to 9), as shown in Figure 4(a), a noticeable difference between the student groups is observed. Most students correctly choose the food items, but they only explain the reasoning for some of the substances contained in the selected foods, rather than all of them (Figure 4, code 4). Students in the experimental group not only select the correct answers but also provide comprehensive explanations that relate to health and the role of food as

an energy source, as shown in Figure 4(b). In contrast, students in the control group, although they select the correct answer at the same rate as the experimental group (60%), offer only a partially correct explanation (Figure 4(a)). Although the flashcards were designed based on teaching materials aligned with learning outcomes according to the national curriculum rather than directly assessing knowledge, a difference in understanding of the taught content is noticeable. It would be beneficial in future research to directly link the content of the flashcards to the material assessed in the final evaluation to establish a clear connection between the flashcard content and its support for learning at specific CLs. Through the flashcards, students learn that fats, which store large amounts of energy, are found in animal-based foods and that food absorbs a significant amount of oil during frying, which serves as a reminder that large quantities of fats are unhealthy. Students who use flashcards frequently select yoghurt as a healthy food choice, which is also linked to the visual support provided by a hint card displaying dairy products. The Mann-Whitney U test indicates a statistically significant difference in problem-solving in all tasks, one reproduction and one conceptual understanding task (Table 2), with the experimental group demonstrating better performance compared to the control group. Otten *et al.* [36] point out that students' knowledge about healthy nutrition and the impact of poor nutrition on human health is weak, and that teachers with less knowledge about healthy living teach students less about such topics, especially healthy nutrition. To enhance and complement this poor knowledge [36] and the limited knowledge demonstrated by students in this study, they need to learn about healthy eating from reliable sources. Utilizing peer-reviewed digital tools, such as flashcards, along with additional explanations and support from teachers during the initial learning phase on this topic, can be beneficial.



	0	1	2	3	4	5	6	7	8	9
Discussion	0.00	0.00	9.68	3.23	61.29	0.00	0.00	12.90	6.45	6.45
Flashcards	6.67	6.67	0.00	0.00	60.00	6.67	3.33	6.67	3.33	6.67

(a)

Cod	Specific biological meaning coding
0	No response
1	Meaningless
2	Incorrect answer: Hot dogs are the best meal because they contain animal-derived substances.
3	Incorrect answer: Chocolate cake is the best meal because it contains many calories stored in fats and sugars.
4	A correct answer, but an incomplete explanation: The student correctly selects the food items but only explains the choice of some, e.g., stating that fruit contains healthy sugar, which is a source of energy.
5	A correct answer with accurate explanation: The student correctly identifies that fruit and yoghurt are healthy snacks suitable for a light meal because do not contain many calories but provide vitamins and minerals. Fruit contains healthy sugars, which are a source of energy, while yoghurt has a low-fat content.
6	Incorrect answer: Vid chooses unhealthy food items because they are less accessible/tasty to him.
7	Partially correct answer: The student selects some correct food items and accurately explains them, but includes some incorrect choices.
8	Correct answer but partial explanation: The student explains that the food items are low in calories but do not provide information on what substances they contain.
9	Correct answer without explanation.

(b)

Figure 4. Systematic justification of the selected food items for breakfast in task 1.3.b; (a) shows the frequency of repetition of a certain code and (b) shows explanation of each code

In task 2.2.b, understanding and connecting various adaptations of living organisms to habitat conditions are examined. Students who did not use flashcards most frequently (55%) failed to explain their chosen answers or only state why they selected the correct answer without justifying other adaptations. In contrast, students studying with flashcards provided accurate and comprehensive explanations of the purposes of other mentioned adaptations (17%), which is directly related to the content on the flashcards. The Mann-Whitney U test indicates that this difference is statistically significant (Table 2), favoring students who used flashcards for studying. Gutowski *et al.* [37] demonstrated that German upper secondary school students think about the successful survival of a species when it adequately adapts to environmental conditions, also they conclude that it is necessary to investigate the change in students' thinking after education about it. Additionally, they concluded that students think about evolution and natural selection in a scientific sense, but depending on their prior knowledge and religious background, they interpret today's knowledge more or less accurately [37]. This finding can be connected to task 2.3.b, which assesses the understanding of adaptations of living organisms under various natural conditions as shown in Figure 5. The Mann-Whitney U test reveals (Table 2) a significant difference in performance between students who used flashcards for learning and those who used traditional methods. Despite the better performance of students using flashcards, 7% chose an incorrect answer, explaining that oil production would be the only way to lift a fish if it loses its swim bladder. However, flashcards in Figure 1 specifically discuss the role of oil in the liver of only some fish. This result

highlights the importance of the teacher's role in the learning process with flashcards which should direct students to pay attention to the cards' contents and their visualization. Another example of improved understanding in the experimental group is found in task 3.3.b, which assesses conceptual understanding of the relationship between water properties and different modes of movement, precisely the difference between passive and active movement. The main distractor in the provided answers was buoyancy. Using flashcards, students learn that buoyancy has a stronger effect on organisms with greater body weight and use this knowledge to justify their answers. There is an 8% difference in partial explanations and a 4% difference in entirely correct explanations about connections between adaptations and water properties among students using flashcards, with the Mann-Whitney U test showing that this difference is statistically significant (Table 2). Dorji [38] has researched that misconceptions are very common when teaching density and buoyancy, and that by using carefully designed visual representations and specific questions, we can reduce the occurrence of misconceptions among students. Taşdere and Kaya [39] suggest that using different teaching methods and techniques embedded in the CKCM instructional model enables students to remedy some misconceptions about the buoyancy force, but does not completely eliminate them, which confirms the complexity of the concept and the value of learning with flashcards which achieved better results of students in this research.

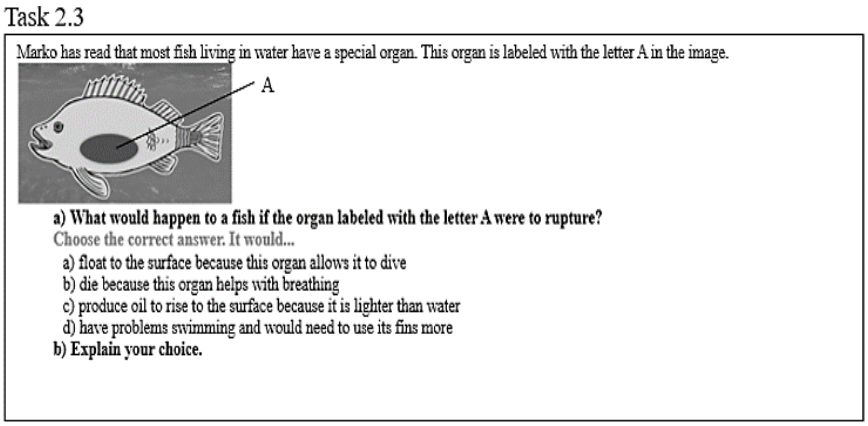


Figure 5. Example of a task from a final knowledge assessment that examines students' knowledge about the adaptations of living beings

3.2. Student opinions on learning with flashcards

Students largely confirm that, by using flashcards, they have reviewed a substantial amount of instructional content quickly, better understand the topics they studied, learn new information, find the learning instructions clear, and easily recognize concepts based on descriptions, as shown in Figure 6. Students' responses in the surveys align with Zarif's *et al.* [40] conclusion that students are motivated to learn with flashcards as one of many e-learning methods. This supports Hariri's *et al.* [41] conclusion that new learning techniques in education encourage students to learn and enhance their motivation.

A moderate correlation was found among students who reported that the instructions for using flashcards were clear and who felt they had independently learned something new from the flashcards ($\rho = 0.40$; $p<0.05$). Similarly, students who found the instructions clear also believed they had quickly reviewed a substantial amount of teaching content ($\rho=0.34$, $p<0.05$). This confirms that students positively perceive the practicality and simplicity of using flashcards when the instructions are clearly defined, i.e., when they are guided through the new learning with flashcards. Most students find revising with flashcards easier than traditional revising methods (Figure 6). Interestingly, a similar result was shown in a large study of medical students regarding student motivation for learning with flashcards [42]. Namely, through four years of monitoring students, they concluded that out of all the tools offered, flashcards are the most popular among the newer generations and that students are most motivated to revise content with digital flashcards [42].

Using Spearman's rank correlation coefficient, a moderate correlation was found between students who frequently used hint cards and those who confirmed that they helped them in concept discovery ($\rho=0.48$; $p<0.05$). This indicates that students with experience using hint cards recognize the potential benefits of such features in digital flashcards. Shields [43] points out that help-seeking behaviors are a critical part of children's ability to regulate their learning and children prefer to seek hints compared than answers. The third open-ended survey question asked which hint cards were most helpful for memorizing concepts. Most students who used

hint cards indicated that a card depicting a light bulb, which reminded them of light energy, was particularly useful for questions on energy conversion (47%). Other students cited individual examples such as a photograph of a swim bladder, a water bubble on the surface of the water, or an opening on a dolphin's body. Students benefit from learning strategies that promote retrieval, which is connected with the development of help-seeking behaviors in children [43], and was also confirmed in this research. The final survey question asked students what they especially liked about flashcards so 13.8% of students appreciated the ability to review a large portion of content quickly interestingly, some mentioned a specific content they learned particularly well, and it is also interesting that 12% of students liked the hint cards as a learning aid. Llumiquinga [25] used hint cards for reproducing English vocabulary with physical flashcards and confirmed that the use of hint cards positively impacted student knowledge. This study demonstrates that hint cards, even in digital form, positively affect learning outcomes, especially in understanding biological concepts. Correlations show that students recognize the potential of hint cards, particularly if they have more experience using them. Moreover, we can conclude that hint cards for concepts not yet mastered provide excellent support for learning biological content, even in digital form.

The limitations of this study are primarily due to the small sample size, which included only one age group of students. As a result, the reliability of the assessments and the survey questionnaire is somewhat low, although still within acceptable limits. Despite this, the current study preliminarily indicates that students using flashcards demonstrate better conceptual understanding and are more successful in solving the second part of the two-layered question. To obtain more comprehensive results on learning with flashcards, it is necessary to extend the research to multiple generations of students and to include more than three sets of flashcards per generation. Additionally, survey data reveal that students respond positively to this form of learning and find the additional feature of hint cards in the digital format beneficial for their learning process. Finally, we can conclude that students are interested in using online tools in the classroom; however, there are challenges with the application of technology that hinder the learning process, leaving room for the development of higher-quality online content and further research on the impact of these resources.

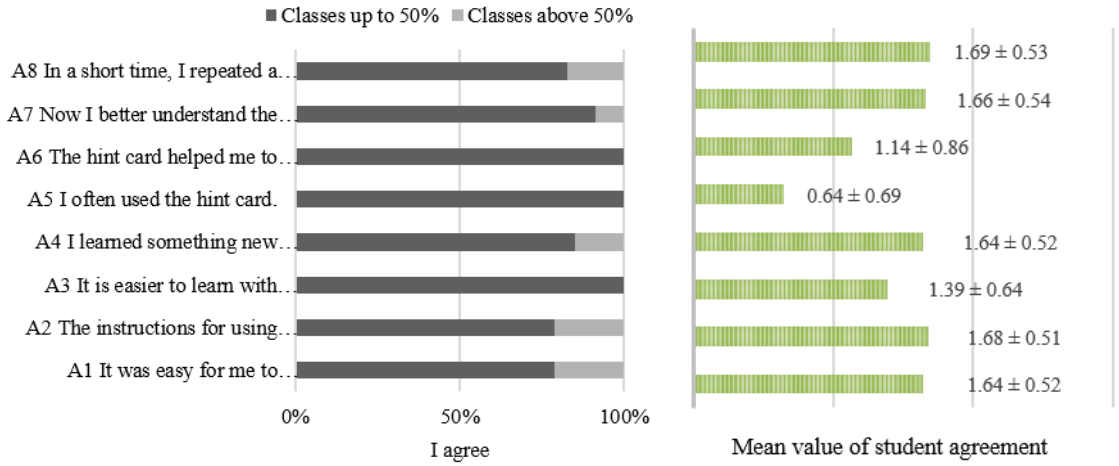


Figure 6. Responses of students who reviewed with flashcards to survey questions

4. CONCLUSION

Based on the research results, it can be concluded that although the experimental group did not perform better in the final assessment, digital flashcards assist students in solving higher-order cognitive tasks. Students hold a positive view of using digital flashcards in learning, finding such revision simple and practical. The additional feature of hint cards is considered beneficial by students for enhancing their understanding. They incorporate the content of these hints into their explanations, which confirms the positive impact of hint cards on the more successful formulation of explanations in biological content. The novelty of this study lies in identifying the positive effect of integrating hint cards into digital flashcards, specifically in how they support students in forming more effective explanations of biological content. This feature appears to be a unique addition not commonly explored in prior flashcard studies, contributing new insights into how tutored approach guidance (in form of hints) within flashcards can enhance higher-order cognitive performance. Despite promising findings, this study's limitations are a single-age cohort and a small sample size. Future studies should increase the sample in a generation and extend the research to different ages of students to increase the

reliability and to compare the impact of flashcards on different generations of students. Additionally, future studies should examine the long-term impact of digital flashcards on retention and explore variations in flashcard design to align closely with curricular standards and learning outcomes.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AP], upon reasonable request.

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