

Educational Crossword Puzzles as A Tool for Engaging Active Learning among Undergraduate Health Professional Students

Nida Suhail^{1*}, S. Anil Mohan Rao², B.V. Padmanabha³, Anshoo Agarwal⁴, Abdul Ghaffar Abdul Rehman⁵, Habeeb Ali Baig⁶, Syed Raziuddin Quadri⁷ and Naglaa M. Shalaby⁸

¹Department of Medical Laboratory Technology, Faculty of Applied Medical Sciences, Northern Border University, Arar, 91431, Saudi Arabia

²Department of Pathology, Faculty of Medicine, Northern Border University, Arar, 91431, Saudi Arabia

³Department of Physiology, Faculty of Medicine, Northern Border University, Arar, 91431, Saudi Arabia

⁴Department of Community Medicine, College of Medicine, Northern Border University, Arar, 91431, Saudi Arabia

⁵Department of Microbiology, Faculty of Medicine, Northern Border University, Arar, 91431, Saudi Arabia

Author Designation: ¹Associate Professor, ²Assistant Professor, ³Assistant Professor, ⁴Professor, ⁵Lecturer, ⁶Assistant Professor, ⁷Assistant Professor, ⁸Professor

*Corresponding author: Nida Suhail (e-mail: nsuhail123@gmail.com).

©2026 the Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)

Abstract Background and Aims: Health professional students are exposed to a vast number of terminologies and concepts within a short academic period, making it challenging to achieve sufficient practice and consistency for effective learning. This study evaluated undergraduate health professional students' perceptions of the usefulness of crossword puzzles as an active teaching-learning strategy to reinforce scientific terminology and concepts. **Methods:** This descriptive, cross-sectional survey study included 375 health professional students who completed a crossword-puzzle learning activity in 2024. Data were collected using a pre-validated, self-structured questionnaire (content validity established by review of three subject-matter experts; internal consistency was not formally assessed) assessing four domains: student engagement, collaborative and competitive features, learning utility and effectiveness in recognizing key concepts and terminology. **Results:** Most students (91%) reported improved recognition of essential terms and concepts, while 85% agreed that crossword puzzles enhanced critical thinking and facilitated discussion. Additionally, 96% perceived crossword puzzles as more effective than other small-group learning methods, particularly for improving spelling accuracy and expanding scientific vocabulary. **Conclusion:** Crossword puzzles were positively perceived by students as an engaging, student-centered supplementary teaching strategy that may support vocabulary acquisition, conceptual understanding and engagement; controlled studies with objective learning outcomes are recommended to confirm their educational effectiveness.

Key Words Crossword Puzzles, Curriculum, Quality Education, Teaching Methodology, Vocabulary

INTRODUCTION

In contemporary health professional education, students are exposed to an array of intricate scientific concepts and terminologies within a brief academic period. This demanding requirement often results in cognitive overload and superficial understanding of the concepts which are essential for internalization of key ideas [1,2].

Traditional instructional strategies may prove effective for imparting fundamental knowledge but might not enhance thinking skills, student engagement or prolonged retention of information [3,4]. Consequently, in the discipline of health sciences, emphasis is placed on the active learning strategies which encourage cognitive depth and strengthen internal

motivation and collaborative learning. Numerous teaching methods are included in active learning where students participate in meaningful educational tasks and evaluate their performance [5]. Game Based Learning (GBL) has emerged as an innovative learning tool that uplifts motivation, interaction and retention of learned material by integrating the aspects of fun and competition [6,7].

Crossword puzzles, a kind of instructional game has demonstrated positive results in improving the vocabulary, memory and encouraging integration of interrelated concepts in the biomedical disciplines [8,9]. Students can actively recall knowledge, identify relationship between phrases and reinforce learning through practice and

discussion because of their structured yet engaging nature [10]. Regardless of the recognized benefits of active and game based learning in health professional education, the implementation of crossword puzzles as an organized teaching-learning tool in undergraduate health sciences curricula is underexplored. Studies have indicated that crossword activities can be a valuable tool in boosting self-evaluation, improving comprehension of medical terms and promoting teamwork [11,12].

The present study was undertaken to assess how well undergraduate health professional students use crossword puzzles as a novel T-L technique to reinforce key scientific terms and concepts.

It provides insight into how students perceive their enjoyment, competitive and collaborative engagement, learning utility and ability to identify and remember important disciplinary vocabulary. By evaluating these perspectives, this study adds to the expanding body of data supporting interactive and student-centered learning techniques in health professional education. Unlike previous reports that have generally examined crossword puzzles within a single subject area or small class setting, the present study evaluates a structured, multi-domain perception framework across a large cohort ($n = 375$) spanning more than one basic-science topic area (Figure 1 and 4), thereby providing a more comprehensive assessment of students' perceived learning utility, collaborative engagement and vocabulary reinforcement associated with this instructional tool.

METHODS

A total of 375 health professional students participated in this study. Data were gathered in 2024 by using a pre-validated, self-structured questionnaire designed to assess students' perceptions of crossword puzzles as a teaching and learning tool. The survey questions were chosen from the topics taught in the health science curriculum. This was a descriptive, cross-sectional study of student perceptions following a single crossword-puzzle learning activity; no comparison group or objective pre-/post-test of knowledge was included and the results should therefore be interpreted as perception data rather than as evidence of an experimentally demonstrated learning effect. The study received ethical approval from the Local Committee of Bioethics at Northern Border University, Arar, Saudi Arabia (Decision No. 30/43/H, dated 02/03/2022). Participant data were collected in 2024. The study followed the principles of the Declaration of Helsinki and its amendments. Participation was voluntary and informed consent was obtained from all participating students after the purpose and objectives of the study were explained.

Participants were recruited via convenience (total-population) sampling: all students enrolled in the relevant 2024 course sessions who were present during the scheduled crossword-puzzle activity were invited to participate and completed the questionnaire in class immediately afterward

(response rate $\approx 100\%$ of students present; a separate count of enrolled students who were absent that day was not tracked). Approximately 60% of respondents were female. Detailed baseline characteristics-age, specific program/discipline, academic year and prior exposure to crossword/game-based learning-were not captured in the original questionnaire and are therefore not reported (Supplementary Table S1); this is acknowledged as a limitation (see Limitations).

The aim of the study was to evaluate students' impression of crosswords across four domains: student satisfaction, collaborative and competitive attributes, learning benefit and usefulness in comprehending important concepts and language.

The 15-item questionnaire was developed by the study investigators, with items mapped a priori to the four conceptual domains listed above; the mapping of individual items to each domain is provided in Supplementary Table S2. Content validity was established through review by three subject-matter experts in health professions education. A separate formal pilot test was not conducted. Internal-consistency reliability (Cronbach's alpha) was not calculated for this descriptive analysis; this is acknowledged as a limitation of the study (Limitations).

Crossword puzzles were developed for selected topics within the health science curriculum. Each student received a printed crossword puzzle, consisting of terms and concepts arranged in horizontal and vertical rows and columns. After completing the puzzles, students filled out the questionnaire to provide feedback on their learning experience.

Two crossword puzzles covering different topic areas were used in the study: one focused on basic biochemical and metabolic concepts (Figure 1, 2) and the other focused on hematology-oncology concepts (Figure 3, 4). The same two crossword puzzles were provided to all groups. Students were randomly assigned to groups of 6-7 participants. All groups received the same standardized instructions from the facilitator and completed the activity within 30 minutes. The crossword puzzles were developed by academically trained professionals, ensuring content accuracy and alignment with course objectives. Each puzzle comprised 10 questions accompanied by a list of potential answers, from which students selected the correct responses and entered them in the appropriate crossword grid spaces. To maintain the difficulty level at an acceptable level, both short and long words were used. From simple to complex, the clues were methodically designed around key phrases that represented major ideas and concepts and their associations. Content validity was ensured by linking all clues and answers directly to the intended learning objectives. The level of difficulty was established by taking into account the participants' understanding of fundamental concepts: Simple recall and rote learning questions were regarded as easy, while questions that required problem-solving and critical thinking skills and application based questions were regarded as challenging.

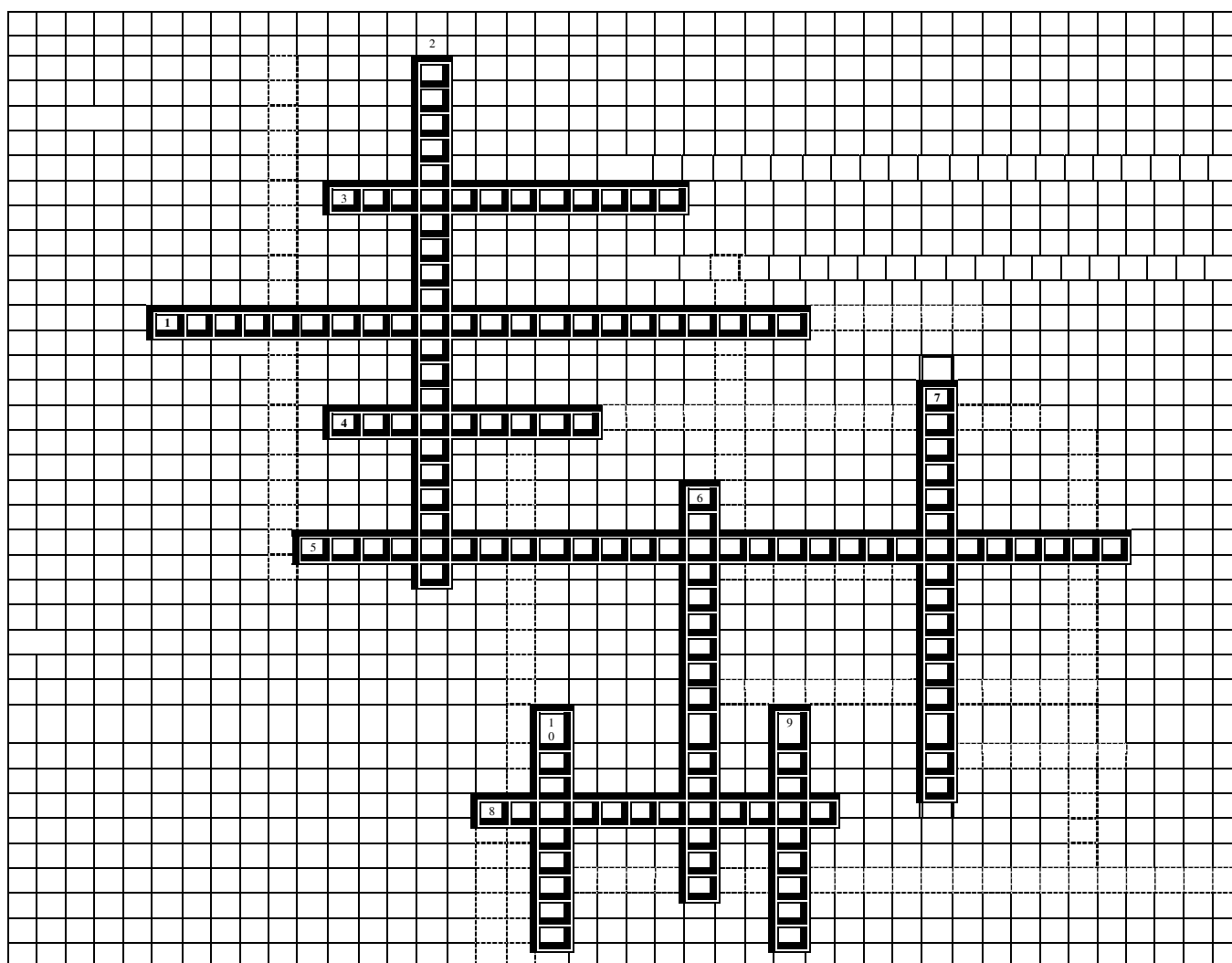


Figure 1: Crossword Grid on Basic Concepts Questions Without Filled Up Answers

Clues**Across**

- 1: Which condition results from insulin resistance and an insulin deficiency in obese patient?
- 3: Which form of severe protein malnutrition is characterized by edema and an enlarged liver with fatty infiltrates?
- 4: Name the form of severe malnutrition characterized by energy and calorie deficiency.
- 5: Name an autosomal recessive metabolic disorder that affects amino acid transport, leading the body's inability to digest and use protein building blocks.
- 8: Name the disorder that occurs from failure to inherit the gene for producing the enzyme homogentisic acid oxidase.

Down

- 2: Name the main inhibitory neurotransmitter in the human brain (other than glutamate, which is primarily excitatory).
- 6: Name the condition caused by high plasma LDL-cholesterol concentrations in the blood.

- 7: Name an enzymatic disorder caused by a mutation of a single amino acid leading to the disruption of the normal conversion of phenylalanine to tyrosine.
- 9: Name severe thiamine-deficiency syndrome found in areas where polished rice is the major component of the diet.
- 10: Name the disease caused by deficiency of Niacin involving the skin, gastrointestinal tract and central nervous system

Answers

- 1: Type 2 Diabetes Mellitus
- 2: Gamma Amino Butyric Acid
- 3: Kwashiorkor
- 4: Marasmus
- 5: Lysinuric protein intolerance
- 6: Atherosclerosis
- 7: Phenylketonuria
- 8: Alkaptonuria
- 9: Beriberi
- 10: Pellagra

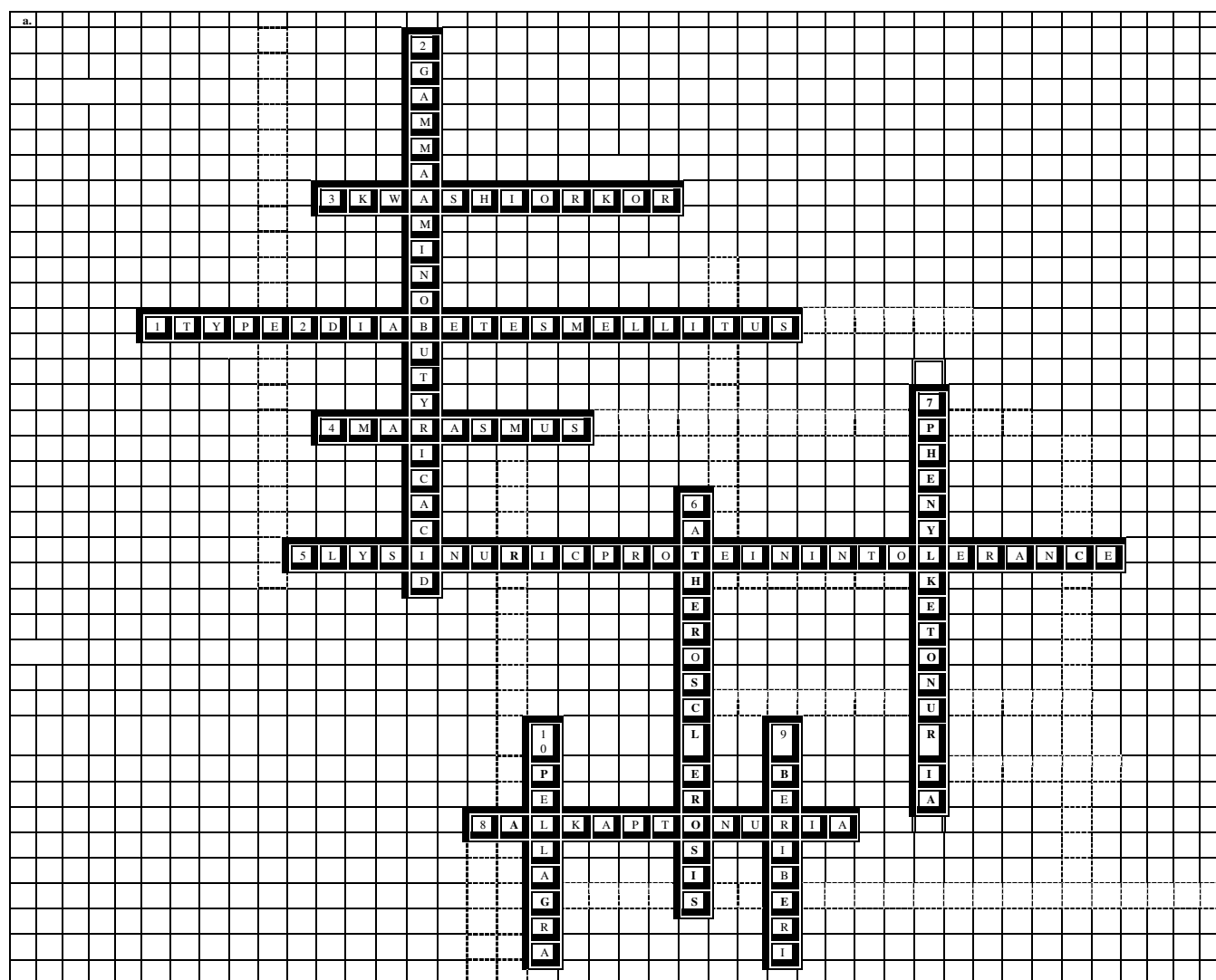


Figure 2: Crossword Grid on Basic Concepts Questions with Filled Up Answers

Each crossword puzzle included typical clues derived from the course content, designed to assess students' understanding of key terms and concepts. The activity was conducted during a 30 minute classroom session, providing adequate time for puzzle completion and subsequent reflection. During the session, students were organized into small groups of six to seven members to encourage collaboration and peer learning. Following completion of the crossword puzzles, the facilitator led a group discussion during which the correct answers were discussed and constructive feedback was provided to the students. Figure 1-4 provide an example of questions given to the students along with answers to be filled in the crossword puzzles made by the subject experts.

Data analysis

For Data analysis, the Statistical Package for Social Sciences (SPSS) was used. Descriptive statistics was performed using frequencies and percentages for categorical variables. A p-value of <0.05 was considered statistically significant.

Individual Likert-scale items were treated as ordinal data and are presented descriptively as frequencies, percentages, means and standard deviations. A one-sample t-test was additionally used to compare the mean response for each item with the neutral midpoint of the scale (3.0); given the recognized debate around parametric analysis of Likert-type data, these comparisons are presented as an exploratory index of the direction and magnitude of agreement rather than as confirmatory evidence of statistically demonstrated learning effectiveness and are interpreted alongside the corresponding means and standard deviations rather than in isolation. Item 11 and Item 14 were negatively worded; consistent with this, lower mean agreement on these two items reflects a favourable perception and they were interpreted in the reverse direction to the remaining items. No composite or domain-level score was calculated in this descriptive analysis (Limitations), so no additional reverse-scoring beyond this interpretive note was required.

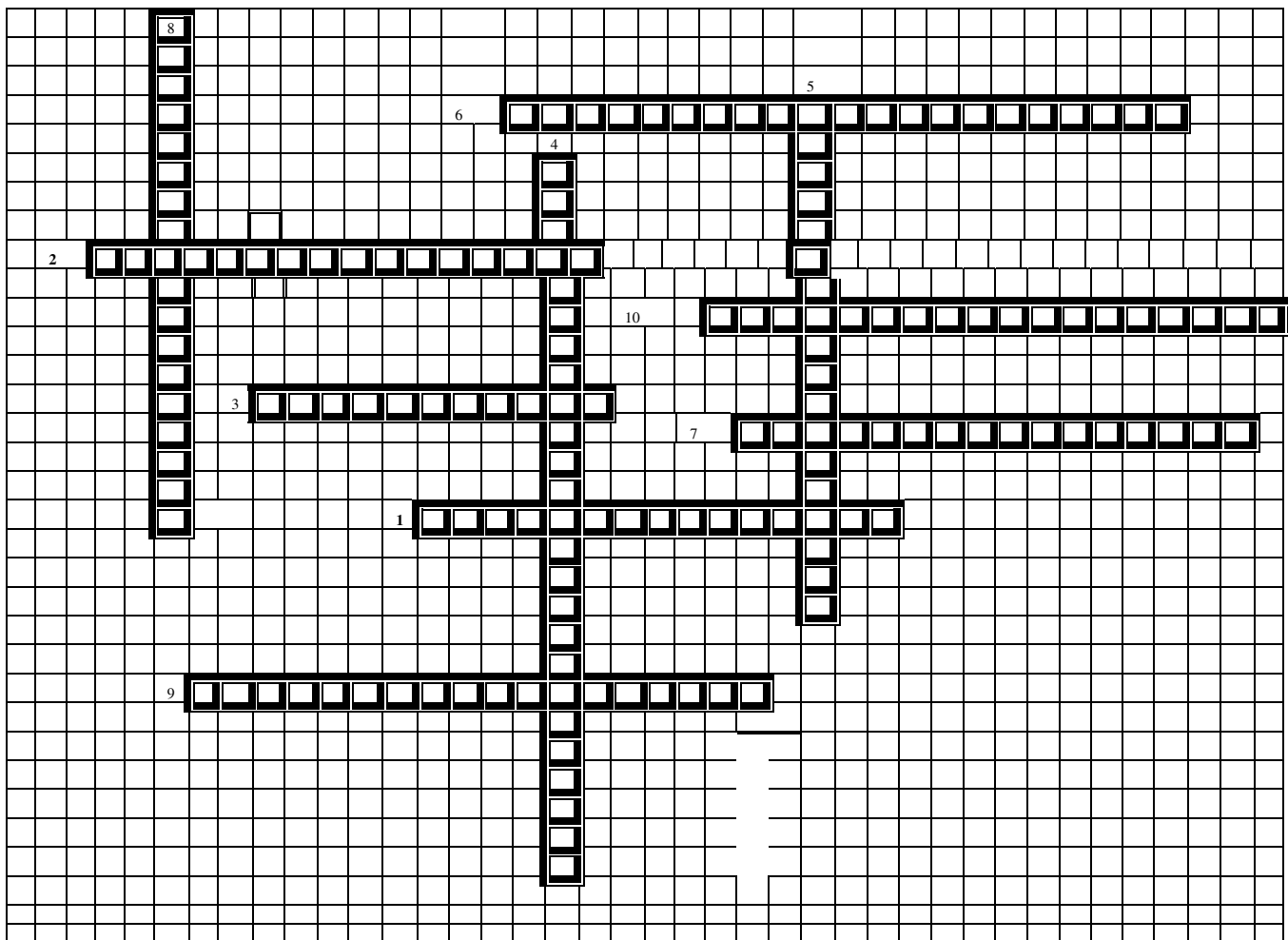


Figure 3: Crossword Grid on Hematology and Neoplasia Questions Without Filled Up Answers

Clues**Across**

- A 23 year old previously healthy man develops moderate to severe hemolytic anemia. Urinalysis shows free hemoglobin and Coombs test is negative. Supravital staining of the blood smear demonstrates Heinz bodies within erythrocytes. Diagnosis?
- A 30 year old woman complains of recent fatigability, bruising and recurrent throat infections. Abnormal laboratory findings include reduced hemoglobin, white blood cell count and platelets. The bone marrow is hypocellular and displays increased fat. Diagnosis?
- 6. In a laboratory exercise, a 23 year-old female was found to have a prolonged bleeding time and a prolonged APPT. Her platelet count was normal. These findings are strongly suggestive of:
- 7. A bone marrow aspiration from a 65 year-old man with long-standing profound anemia shows megaloblastic erythroid hyperplasia and presence of hypersegmented neutrophils in peripheral blood smear. Diagnosis?
- 9. A 5 year-old African boy develops a rapidly enlarging mass that involves the right side of his face. Biopsies reveal a prominent 'starry sky' pattern produced by proliferating small, noncleaved malignant lymphocytes. Which virus is most closely associated with this malignancy?

- 10. Which malignancy is strongly associated with Chinese liver fluke infestation?

Down

- 3. Mycosis fungoides represents a malignancy of: _____
- 4. The mammogram of a 44 year-old female shows several 0.5-1.5 cm foci of irregular density in both breasts. Fine needle aspirates of lesions in both breasts show malignant cells. Diagnosis?
- 5. Which carcinoma is locally invasive but rarely forms metastases in lymph nodes and distant sites?
- 8. Most non-neoplastic polyps of the stomach are microscopically classified as: _____

Answers

- 1: G6PD deficiency
- 2: Aplastic anemia
- 3: T lymphocyte
- 4: Infiltrating duct carcinoma
- 5: Basal cell carcinoma
- 6: Von willebrand disease
- 7: Pernicious anemia
- 8: Hyperplastic polyps
- 9: Epstein-barr virus
- 10: Cholangiocarcinoma

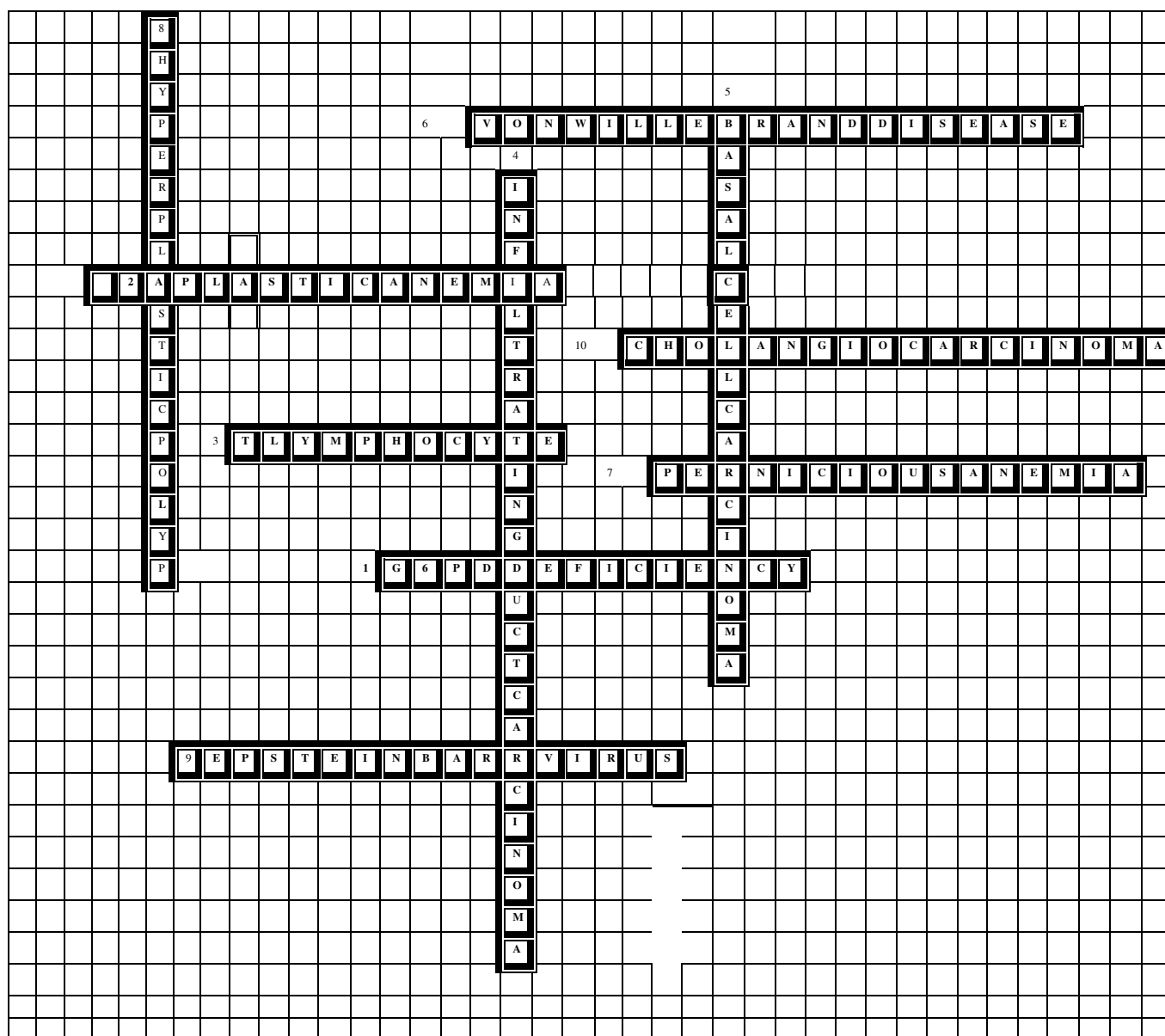


Figure 4: Crossword Grid on Hematology and Neoplasia Questions with Filled Up Answers

RESULTS

A crossword puzzle activity was created for students enrolled in health science courses and their perceptions of the activity were assessed through a structured questionnaire (Table 1). The majority of participants (95%) reported that the crossword puzzles were extremely helpful in improving their comprehension of the core concepts and were willing to engage in similar activities in the future. Furthermore, 95% of respondents reported that the crossword puzzles helped them recognize and remember important words and ideas. Approximately 91% of those surveyed stated that they would recommend this approach to their juniors and ask instructors to use it as a method of instruction. While a small proportion of participants indicated that additional time was needed to answer these kinds of puzzles, 85% of them agreed that tackling crossword puzzles gave them the chance to explore important ideas and exercise critical thinking.

About 96% of students reported that crossword puzzle exercises were beneficial when compared with other small-group learning techniques, especially for improving spelling accuracy and broadening their vocabulary of scientific terms. Most participants also indicated that collaborative problem-solving during the exercise strengthened conceptual understanding from a variety of angles and encouraged knowledge integration and that the activity created an interesting and dynamic learning environment. Additionally, 94% of participants strongly agreed that the crossword sessions promoted quick team building by providing a challenging but relaxed task that boosted group members' confidence and collaboration. Remarkably, 98% of participants said that the crossword exercise helped them focus on important details of the topic (Table 1).

Table 1: Questionnaire Items Assessing Students' Perceptions of Crossword Puzzles in Health Science Courses

S. No	Items	Strongly disagree (n(%))	Disagree (n(%))	Neither agree nor disagree (n(%))	Agree (n(%))	Strongly agree (n(%))	Mean	SD	p-value
1	Did the crossword puzzles help you learn something new?	-	2 (1)	2 (1)	15 (4)	356 (95)	4.93	0.32	<0.001
2	Did crosswords help you find important terminology and concepts?	-	4 (1)	4 (1)	11 (3)	356 (95)	4.92	0.40	<0.001
3	Do you want to continue doing these exercises?	-	8 (2)	11 (3)	341 (91)	15 (4)	3.97	0.39	<0.001
4	Do you want to recommend your juniors this new crossword puzzle as a learning tool?	8 (2)	11 (3)	-	341 (91)	15 (4)	3.92	0.59	<0.001
5	Would you like to ask all other faculty members teaching you to use it as an additional learning-teaching tool?	-	7 (2)	8 (2)	360 (96)	-	3.94	0.30	<0.001
6	While completing crossword puzzles, could you recall and think critically about the concept asked in the question?	-	-	-	319 (85)	56 (15)	4.15	0.36	<0.001
7	Were the crossword puzzles useful to you in relation to other small-group activities in helping you learn the topic and remember spellings?	7 (2)	8 (2)	-	360 (96)	-	3.90	0.49	<0.001
8	Has it enabled you to comprehend the facts and enabled you to integrate the related information from different subjects undertaken in basic science courses.	-	8 (2)	8 (2)	326 (87)	34 (9)	4.03	0.44	<0.001
9	Have you got the chance for strong team development because of working together to solve the crosswords puzzles exercises?	7 (2)	7 (2)	-	353 (94)	8 (2)	3.93	0.51	<0.001
10	Has this exercise given you an opportunity to face the challenge and allowed you to perform better relying on team members helping to boost your confidence?	-	-	-	311 (83)	64 (17)	4.17	0.38	<0.001
11	Did you feel that solving crossword puzzles caused poor use of class time and due to lack of a traditional teaching approach, this exercise was not appropriate teaching tool?	49 (13)	286 (76)	-	20 (5)	20 (5)	2.14	0.90	<0.001
12	Do you think that due to amusement and fun involved in solving crossword puzzles together, it helped to lighten the mood in the classroom and made learning environment better.	20 (5)	20 (5)	-	276 (74)	59 (16)	3.89	0.92	<0.001
13	Do you think that the crossword puzzle helped you in determining the key areas of the course topics?	-	-	-	368 (98)	8 (2)	4.02	0.14	<0.001
14	Do you think that the crossword puzzles were too easy so not of use?	8 (2)	367 (98)	-	-	-	1.98	0.14	<0.001
15	Do you think that the crossword puzzles were challenging and helped you develop critical thinking skills and strong vocabulary?	8 (2)	8 (2)	8 (2)	351 (94)	-	3.87	0.53	<0.001

N: Frequency (Number of participants), %: Percentage of participants, n = 375, Mean and SD calculated based on 5-point Likert scale (1: Strongly Disagree, 5: Strongly Agree), p-values calculated using one-sample t-test against neutral value of 3.0, Items 11 and 14 are negatively worded, lower mean scores for these two items indicate more favourable perceptions rather than disagreement with the overall utility of crossword puzzles, Domain-level summary scores and reliability coefficients (Cronbach's α) were not calculated for this descriptive analysis (Limitations), The "S. No." column has been retained pending the journal's formatting preference

DISCUSSION

In the framework of small-group teaching, crossword puzzles are an example of a more student-centered approach that necessitates participation and interaction from learners [13]. Activities in small groups encourage more profound understanding, problem-solving, personal accountability for learning and the development of intercultural and interpersonal teamwork [14]. Small-group learners tend to show stronger academic achievement and a more optimistic outlook towards learning [15]. In the present study, 94% of those surveyed strongly agreed that the crosswords provided opportunities for speedy team building and that the exercise gave them an overwhelming feeling of challenge, pushing them to perform and count on team members without any pressure, which boosted their confidence. About 98% of respondents in the study highly reported that the crossword tool assisted them in determining the key points of the subject.

Crossword puzzles gave students immediate feedback by promptly evaluating their current grasp of understanding in an informal manner [16]. This is consistent with the results of earlier gamification-related studies on active learning [17-21]. The questions' replies are concept-based hints that aid in vocabulary reinforcement and help pupils retain the material for longer time. Crosswords have been used for educational settings [17,22]. It is remarkable that more studies and applications of this kind of approach have not been uncovered. A plausible reason for this could be because some educators believe that the usage of games is not adequately looked over and that developing topic-specific, appropriate crosswords takes an excessively long time. Because crosswords don't seem like traditional teaching and could be viewed as an improper use of class time, some people may despise them and view them as non-educational [23]. A few studies have suggested that students' liking of this seldom utilized tool may be due to the fact that puzzles make the classroom more enjoyable by offering comedy, intellectual stimulation, a sense of accomplishment when the task is finished and a connection between the exercise and general learning [24]. In the current study, 95% of students agreed that the crosswords were extremely helpful in identifying important terminology and concepts and had made a big difference in their understanding. The use of crossword puzzles in educational settings is seen to have several advantages [25]. Another self-correcting feature of crossword puzzles is that if a word fits, it fits; if not, it is incorrect. Our aim has been to maintain these puzzles challenging enough for the students to "stretch"—that is, to find them just a bit too difficult for them to solve. As an answer to the question in puzzle is partially accomplished, specific letters in specific positions are found to provide hints [26].

Findings from an earlier study provided insight that students feel a sense of accomplishment when they solve and finish a crossword puzzle because the exercises are difficult and it tests their ability to learn about, visualize, forecast and

solve the puzzle's clues, which increases their self-confidence [27]. In another study, there was no discernible difference between learners who utilized crossword puzzles and those who did not use them in the courses taken by them and no change was found in the scores obtained by students in the final assessments, thereby, questioning the usefulness of crosswords in students learning as reflected by final grades obtained by them [28]. This emphasizes the need to study further as how educational games could support and engage a particular class of learners and improve their performance because there is a greater variation in learning styles among students nowadays [24,29,30]. In the present study, 91% of those surveyed stated that additional time was needed to answer these kinds of puzzles, 85% of them agreed that tackling crosswords gave them the chance to explore important ideas and exercise critical thinking.

When compared to other small group activities, 96% of students agreed that crosswords were helpful, particularly because they helped them understand how to spell correctly and broadened their vocabulary. Solving puzzles together also made the educational environment more enjoyable and entertaining while allowing the students to integrate information and demonstrate their understanding of various points of view [31-33]. In the present educational environment, it is essential that educators provide programs that guide students how to put their scientific knowledge into practice [34]. Since the introduction of active learning interventions, students' performance in many courses has improved, as seen by increased average scores and a closing gap between the highest and lowest grades [35].

According to Kirkpatrick's approach, the effectiveness of instructional programs and learning interventions can be evaluated at several levels, including behavior, learning, reactions and results [36]. A positive correlation between assessments and concepts covered in puzzles and games has been reported by previous studies [37]. Despite the fact that we have not explicitly linked crossword components to exam topics, students' clinical and analytical reasoning skills have been evaluated using an extended matching crossword problem. Future research in this area could investigate the impact of crossword puzzles on students' retention of terminology and conceptual understanding in undergraduate health professions education. Further studies should also examine their influence on teamwork and critical thinking skills and conduct unbiased evaluations to substantiate the effectiveness of this instructional tool in health professions education.

It is important to distinguish clearly between the two levels of evidence reported here. The quantitative results (Table 1) describe students' self-reported perceptions and reactions to the crossword-puzzle activity—that is, Kirkpatrick Level 1 (reaction) evidence—rather than objectively measured learning gains, retention or examination performance (Kirkpatrick Levels 2-4), which were not assessed in this study. High levels of self-reported enjoyment and perceived usefulness do not, by themselves,

establish that crossword puzzles improve measurable learning outcomes; prior studies cited above have reported mixed findings when objective outcomes were examined [27,28]. In addition, because participants were recruited from a single institution using convenience sampling rather than a randomized or multi-institutional sample, the findings may not generalize to other student populations, curricula or health professional disciplines. Controlled, multi-site studies that pair self-reported perceptions with objective, examination-linked outcome measures are needed before firm conclusions can be drawn about the educational effectiveness of crossword puzzles in this setting.

CONCLUSIONS

Crossword puzzles were positively perceived by students in this large, single-institution cohort as an engaging addition to conventional teaching methods, particularly when implemented within a welcoming, competitive and collaborative environment. Students reported that the activity helped them recall and discuss important scientific terminology, while also fostering self-perceived critical thinking, teamwork and healthy competition. As this study assessed self-reported perceptions rather than objectively measured learning outcomes, these findings should be interpreted as evidence that students found crossword puzzles engaging and useful, rather than as confirmed evidence of improved learning; controlled, multi-institutional studies with objective outcome measures are needed to substantiate the educational effectiveness of this instructional tool.

Limitations

This study has several limitations that should be considered when interpreting the findings. First, no control or comparison group was included and no objective pre-/post-test of knowledge or examination-linked outcome was used; consequently, the study demonstrates students' perceptions of, rather than objectively demonstrated improvement in, learning. Second, all outcomes were based on self-report, which may be subject to response bias and social-desirability bias. Third, the study was conducted at a single institution, which may limit the generalizability of the findings to other curricula and teaching contexts. Fourth, participants were recruited via convenience (total-population) sampling from students present during the scheduled activity rather than a randomly selected sample and detailed baseline characteristics-age, specific program, academic year and prior exposure to game-based learning-were not captured (Supplementary Table S1); this limits assessment of how representative the sample was of the broader eligible student population. Fifth, perceptions were assessed immediately after a single crossword-puzzle session, so the durability of any perceived benefit over time is unknown. Finally, internal-consistency reliability (Cronbach's alpha) of the questionnaire was not formally assessed in this study, which

limits conclusions about the psychometric robustness of the instrument and is an important target for future work.

Ethical Approval and Informed Consent

The study received ethical approval from the Local Committee of Bioethics at Northern Border University, Arar, Saudi Arabia (Decision No. 30/43/H, dated 02/03/2022). Participant data were collected in 2024. The study followed the principles of the Declaration of Helsinki and its amendments. Participation was voluntary and informed consent was obtained from all participating students after the purpose and objectives of the study were explained.

REFERENCES

- [1] Sweller, J. "Cognitive Load Theory and Educational Technology." *Educational Technology Research and Development*, vol. 68, no. 1, 2020, pp. 1-6.
- [2] Kalyuga, S. "Evolutionary Perspective on Human Cognitive Architecture in Cognitive Load Theory: A Dynamic, Emerging Principle Approach." *Educational Psychology Review*, vol. 35, no. 3, 2023.
- [3] Prince, M. "Does Active Learning Work? A Review of the Research." *Journal of Engineering Education*, vol. 93, no. 3, 2004, pp. 223-231.
- [4] Michael, J. "Where's the Evidence That Active Learning Works?" *Advances in Physiology Education*, vol. 30, no. 4, 2006, pp. 159-167.
- [5] Lim, S.P. *et al.* "Mobile Gaming in Education: A Bibliometric Analysis of Trends and Performance." *International Journal of Evaluation and Research in Education*, vol. 14, no. 4, 2025, pp. 2676-2685.
- [6] Riemer, V. and C. Schrader. "Learning with Quizzes, Simulations and Adventures: Students' Attitudes, Perceptions and Intentions to Learn with Different Types of Serious Games." *Computers & Education*, vol. 88, 2015, pp. 160-168.
- [7] Zainuddin, Z. *et al.* "The Role of Gamified E-Quizzes on Student Learning and Engagement: An Interactive Gamification Solution for a Formative Assessment System." *Computers & Education*, vol. 145, 2020.
- [8] Saxena, A. *et al.* "Crossword Puzzles as a Learning Tool in Medical Education." *International Journal of Applied and Basic Medical Research*, vol. 9, no. 4, 2019, pp. 222-225.
- [9] D'Antoni, A.V. *et al.* "Does the Mind Map Learning Strategy Facilitate Information Retrieval and Critical Thinking in Medical Students?" *BMC Medical Education*, vol. 10, no. 1, 2010.
- [10] Zamani, P. *et al.* "The Use of Crossword Puzzles as an Educational Tool." *Journal of Advances in Medical Education & Professionalism*, vol. 9, no. 2, 2021.
- [11] Akl, E.A. *et al.* "The Effect of Educational Games on Medical Students' Learning Outcomes: A Systematic Review: BEME Guide No. 14." *Medical Teacher*, vol. 32, no. 1, 2010, pp. 16-27.
- [12] Raines, D. "A Fun Way to Learn Terminology: The Crossword Puzzle." *Nursing for Women's Health*, vol. 11, no. 1, 2007, pp. 29-31.
- [13] Bryant, J. "Crossword Puzzles—Entertaining Tool to Reinforce Lecture Content in Undergraduate Physiology Teaching." *International Journal of Biomedical Research*, vol. 7, no. 6, 2016, pp. 346-349.

- [14] Blouin, R.A. *et al.* "Preparing for a Renaissance in Pharmacy Education: The Need, Opportunity and Capacity for Change." *American Journal of Pharmaceutical Education*, vol. 72, no. 2, 2008.
- [15] Mosalanejad, L. and S.A. Abdollahifar. "Put Aside the Traditional Classroom and Use Effective Technology: Puzzles—Entertaining Ideas for Educating Psychiatric Diseases." *Pakistan Journal of Medical & Health Sciences*, vol. 13, 2019, pp. 519-524.
- [16] de Lima Junior, M.M. *et al.* "Crossword Puzzles: Review and Implication in Urogynecology Education." *Academy of Medical Journal of India*, vol. 2, no. 3, 2014, pp. 87-91.
- [17] Shah, S. *et al.* "Crossword Puzzles as a Tool to Enhance Learning about Anti-Ulcer Agents." *American Journal of Pharmaceutical Education*, vol. 74, no. 7, 2010.
- [18] Htwe, T.T. *et al.* "Basic Science Courses Crossword Competition: An Active and Easy Way of Learning Basic Science Courses in Undergraduate Health Professional Education." *Singapore Medical Journal*, vol. 53, no. 2, 2012, pp. 121-123.
- [19] Saxena, A. *et al.* "Crossword Puzzles: Active Learning in Undergraduate Basic Science Courses and Health Professional Education." *Archives of Pathology & Laboratory Medicine*, vol. 133, 2009, pp. 1457-1462.
- [20] Coticone, S.R. "Utility of Self-Made Crossword Puzzles as an Active Learning Method to Study Biochemistry in Undergraduate Education." *Journal of College Science Teaching*, vol. 42, no. 4, 2013, pp. 38-42.
- [21] Kim, K. *et al.* "Effects of Active Learning on Enhancing Student Critical Thinking in an Undergraduate General Science Course." *Innovative Higher Education*, vol. 38, no. 3, 2013, pp. 223-235.
- [22] Jaramillo, C.M. *et al.* "Designing and Solving Crossword Puzzles: Examining Efficacy in a Classroom Exercise." *Developments in Business Simulation and Experiential Learning*, vol. 39, 2012, pp. 213-222.
- [23] Marcondes, F.K. *et al.* "A Puzzle Used to Teach the Cardiac Cycle." *Advances in Physiology Education*, vol. 39, no. 1, 2015, pp. 27-31.
- [24] Saran, R. and S. Kumar. "Use of Crossword Puzzle as a Teaching Aid to Facilitate Active Learning in Dental Materials." *Indian Journal of Applied Research*, vol. 5, no. 4, 2015, pp. 456-457.
- [25] Kalyani, P. "Crosswords as a Learning Tool in Anatomy & Physiology Teaching." *Medical Teacher*, vol. 29, no. 5, 2007.
- [26] Gaikwad, N. and S. Tankhiwale. "Crossword Puzzles: Self-Learning Tool in Pharmacology." *Perspectives on Medical Education*, vol. 1, no. 5, 2012, pp. 237-248.
- [27] Barclay, S.M. *et al.* "Educational Card Games to Teach Pharmacotherapeutics in an Advanced Pharmacy Practice Experience." *American Journal of Pharmaceutical Education*, vol. 75, no. 2, 2011.
- [28] Rodenbaugh, H.R. *et al.* "Having Fun and Accepting Challenges Are Natural Instincts: Jigsaw Puzzles to Challenge Students and Test Their Abilities While Having Fun!" *Advances in Physiology Education*, vol. 38, no. 2, 2014, pp. 185-186.
- [29] Davis, T.M. *et al.* "Reviewing for Exams: Do Crossword Puzzles Help in the Success of Student Learning?" *Journal of Effective Teaching*, vol. 9, no. 3, 2009, pp. 4-10.
- [30] Kalkan, N. *et al.* "Views of Students on the Use of Crossword and Word Search Puzzle as a Teaching Technique in Nursing Education: A Mixed-Method Study." *Nurse Education Today*, vol. 119, 2022.
- [31] Aghari, R. "The Nature of Educational Reform and Change: From Teacher-Centered to Student-Centered Learning." *Educational Quest—An International Journal of Education and Applied Social Sciences*, vol. 7, no. 2, 2016, pp. 133-139.
- [32] Oyelana, O.O. *et al.* "An Evolutionary Concept Analysis of Learner-Centered Teaching." *Nurse Education Today*, vol. 108, 2022.
- [33] Kaynak, S. *et al.* "The Effect of Crossword Puzzle Activity Used in Distance Education on Nursing Students' Problem-Solving and Clinical Decision-Making Skills: A Comparative Study." *Nurse Education in Practice*, vol. 69, 2023.
- [34] Gómez-Urquiza, J.L. *et al.* "The Impact on Nursing Students' Opinions and Motivation of Using a 'Nursing Escape Room' as a Teaching Game: A Descriptive Study." *Nurse Education Today*, vol. 72, 2019, pp. 73-76.
- [35] Biehle, L. and M. Jeffres. "Play Games and Score Points with Students." *The Clinical Teacher*, vol. 15, no. 6, 2018, pp. 445-450.
- [36] Kirkpatrick, D. and J. Kirkpatrick. *Evaluating Training Programs: The Four Levels*. Berrett-Koehler Publishers, 2006.
- [37] Bedrikow, R. and G.W. Campos. "Clinic: The Art of Balancing Disease and Subject." *Revista da Associação Médica Brasileira*, vol. 57, 2011, pp. 610-613.

Table S1: Baseline Demographic and Academic Characteristics of Participants (N = 375)

Characteristic	Value
Total participants analysed (n)	375
Recruitment/sampling method	Convenience (total-population) sampling: all students enrolled in the relevant 2024 course sessions who were present during the scheduled crossword-puzzle activity were invited to participate.
Response rate	Approximately 100% of students present completed the questionnaire, as it was administered in class immediately after the activity. A separate count of enrolled students who were absent that day was not tracked.
Sex (n (%)) — Female	≈ 60%
Sex (n (%)) — Male	≈ 40%
Age (years)	Not separately recorded in the dataset.
Program/discipline	Not disaggregated; participants were drawn from health-professional programs at Northern Border University and analysed as a single combined cohort.
Academic year	Not disaggregated in the dataset.
Prior exposure to crossword/game-based learning	Not assessed by the questionnaire.

N: Number; %: Percentage of respondents, Sex distribution is reported as approximate percentages, Age, program, academic year and prior game-based-learning exposure were not captured by the study questionnaire, their absence is noted as a limitation in the manuscript (see Limitations section)