Interactive e-learning module on liver ischemia: enhancing medical education on antioxidant defense mechanisms

Zumrud Abaszade, Rana Jabbar Karimova 2nd, Aytan Yagub Mammadzada, Aynur Hajikhalil Ansarova 4th, Shalala Garib Ismayilova 5th, Shahana Gazanfar Gurbanova 6th

Submitted to: JMIR Medical Education
on: August 21, 2025

Table of Contents

Interactive e-learning module on liver ischemia: enhancing medical education on antioxidant defense mechanisms

Zumrud Abaszade[1] A; Rana Jabbar Karimova 2nd[2] A; Aytan Yagub Mammadzada[1] A; Aynur Hajikhalil Ansarova 4th[3] A; Shalala Garib Ismayilova 5th[3] A; Shahana Gazanfar Gurbanova 6th[4] A

[1] Department of Internal Medicine Azerbaijan Medical University Baku AZ
[2] Scientific Research Center Azerbaijan Medical University Baku AZ
[3] Department of Medical Biology and Genetics Azerbaijan Medical University Baku AZ
[4] Department of Cytology, Embryology and Histology Azerbaijan Medical University Baku AZ

Corresponding Author:
Zumrud Abaszade A

Department of Internal Medicine
Azerbaijan Medical University
Azerbaijan
Baku
AZ

Abstract

Background: Liver ischemia-reperfusion injury is one of the critical biochemical and clinical issues in hepatology; however, its education is weak because of the complexity of the oxidative stress and antioxidant defenses mechanism. It is often the case that the traditional lecture-based instruction strategies cannot guarantee long-term retention or translational of the knowledge to the clinic, creating a disconnect between knowledge theory and on-the-job training. Closing this gap is necessary since ischemia-related complications are one of the main morbidity and mortality factors after liver surgery and transplantation.

Objective: The purpose of the study was to design and compare an interactive e-learning session with of improving medical-students understanding of liver ischemia and antioxidant defense, with lecture-based teaching.

Methods: A pilot study has been carried out at Azerbaijan Medical University with sixty third year medical students randomly divided into a control group (lecture-based) and an experimental-group (interactive e-learning). Knowledge acquisition and retention were measured using pre-tests, immediate post-tests and follow-up tests after two and four weeks. Engagement and clinical relevance were determined by means of validated surveys. The statistical analysis was conducted with paired t -tests and ANOVA.

Results: The e-learning group exhibited a +74.3 percent relative increase in knowledge scores (42.4 ± 3.3 to 78.8 ± 3.3, $p < 0.01$), and retention that was unchanged at four weeks (70.0 +/- 2.9). Conceptual comprehension was enhanced by 93.7 % ($p < 0.01$), and there was a win increase in student engagement of 64.6 % ($p < 0.01$). The application to clinical cases increased more than twice as much (+110.2%, $p < 0.01$). The control group only had minor improvements, with retention of 49.5 + 4.9 after Four weeks. Biological data in the form of complementary biochemical-analyses in ischemia models supported significant time related damage in protein metabolism especially in the situation of prolonged ischemia.

Conclusions: ctive module was significantly better than lecture-based in promoting knowledge acquisition, retention, and utilization in clinical practice. The results indicate the potential of the module as a scalable and effective pedagogical innovation in the medical learning environment and toward a more robust clinical preparation. Clinical Trial: no registration number

(JMIR Preprints 21/08/2025:82797)
DOI: https://doi.org/10.2196/preprints.82797

Preprint Settings

1) Would you like to publish your submitted manuscript as preprint?
✓ **Please make my preprint PDF available to anyone at any time (recommended).**

Please make my preprint PDF available only to logged-in users; I understand that my title and abstract will remain visible to all users.
Only make the preprint title and abstract visible.
No, I do not wish to publish my submitted manuscript as a preprint.

2) If accepted for publication in a JMIR journal, would you like the PDF to be visible to the public?

✔ **Yes, please make my accepted manuscript PDF available to anyone at any time (Recommended).**
Yes, but please make my accepted manuscript PDF available only to logged-in users; I understand that the title and abstract will remain v
Yes, but only make the title and abstract visible (see Important note, above). I understand that if I later pay to participate in <a href="http
No. Please do not make my accepted manuscript PDF available to anyone. I understand that if I later pay to participate in <a href="https:/

Original Manuscript

Interactive e-learning module on liver ischemia: enhancing medical education on antioxidant defense mechanisms

ABSTRACT

Introduction: Liver ischemia-reperfusion injury is one of the critical biochemical and clinical issues in hepatology; however, its education is weak because of the complexity of the oxidative stress and antioxidant defenses mechanism. It is often the case that the traditional lecture-based instruction strategies cannot guarantee long-term retention or translational of the knowledge to the clinic, creating a disconnect between knowledge theory and on-the-job training. Closing this gap is necessary since ischemia-related complications are one of the main morbidity and mortality factors after liver surgery and transplantation.

Objectives: The purpose of the study was to design and compare an interactive e-learning session with of improving medical-students understanding of liver ischemia and antioxidant defense, with lecture-based teaching.

Methods: A pilot study has been carried out at Azerbaijan Medical University with sixty third year medical students randomly divided into a control group (lecture-based) and an experimental-group (interactive e-learning). Knowledge acquisition and retention were measured using pre-tests, immediate post-tests and follow-up tests after two and four weeks. Engagement and clinical relevance were determined by means of validated surveys. The statistical analysis was conducted with paired t -tests and ANOVA.

Results: The e-learning group exhibited a +74.3 percent relative increase in knowledge scores (42.4 ± 3.3 to 78.8 ± 3.3, $p < 0.01$), and retention that was unchanged at four weeks (70.0 +/- 2.9). Conceptual comprehension was enhanced by 93.7 % ($p < 0.01$), and there was a win increase in student engagement of 64.6 % ($p < 0.01$). The application to clinical cases increased more than twice as much (+110.2%, $p < 0.01$). The control group only had minor improvements, with retention of 49.5 + 4.9 after Four weeks. Biological data in the form of complementary biochemical-analyses in ischemia models supported significant time related damage in protein metabolism especially in the situation of prolonged ischemia.

Conclusion: Active module was significantly better than lecture-based in promoting knowledge acquisition, retention, and utilization in clinical practice. The results indicate the potential of the module as a scalable and effective pedagogical innovation in the medical learning environment and

toward a more robust clinical preparation.

Keywords: Antioxidants, E-learning, Hepatic ischemia, Medical education, Protein metabolism

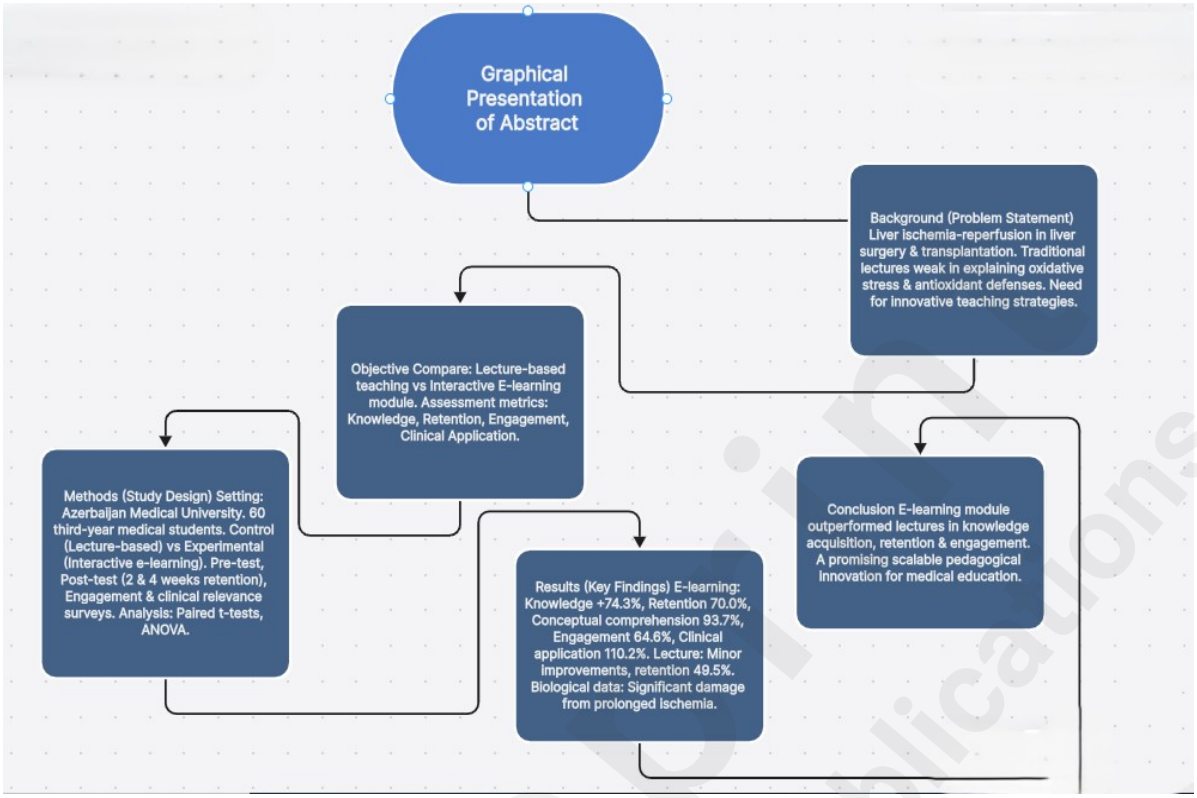

Figure 1: e-Learning Module on Liver Ischemia: A Comparative Approach to Enhancing Medical Education on the Antioxidant Defense Mechanisms

The given graphical abstract explains the design of a pilot study carried out at the Azerbaijan Medical University as well as the results of the same (Figure 1). Sixty medical students were randomly divided into groups of lecture and interactive e-learning. It showed significantly high values of knowledge gain, retention, engagement, and clinical application than the traditional lectures proving very effective and worthwhile of application in the interactive e-learning module setup. The results indicate e--learning as an amplifiable innovation to fulfil the void between theoretical training and clinical training in hepatology training.

INTRODUCTION

The liver is one of the most metabolically active of the human body organs where protein metabolism, detoxification, energy control and system homeostasis all intersect [1,2]. The familiarity of ischemic injury is related to its higher metabolic requirement and profound vascular supply [3]. Hepatic ischemia followed by hepatic reperfusion leads to a sequence of molecular and cellular

pathophysiology comprising of oxidative stress, mitochondrial dysfunction and overrun of reactive oxygen species (ROS) [4]. All these processes collectively interfere with protein metabolism, cellular bioenergetics and in the face of unabsorbed, indeed uncontrolled, lead, these phenomena culminate in hepatocellular necrosis and fatty hepatocellular degeneration [5]. These biochemical and molecular pathways have been widely studied within the discipline of biomedical science but they are in themselves quite complex and hence there are some barriers to effective teaching these processes at medical and biochemistry undergraduate level [6].

Scope of the study and Background

Liver ischemia-reperfusion injury (IRI) is not only a basic biochemical issue, but also a clinically significant one being observed in surgical operation of liver resection, transplantation, and trauma treatment [7,8]. The world is facing increasing hepatic disease burden and bouts of ischemia-associated diseases are one of the primary causes of morbidity and death [9]. In developed healthcare systems, the role of ischemic complications as a device in the progression of postoperative liver malfunction is one of the leading issues, whereas in resource-limited parts of the world, the lack of perioperative care increases the risks faced by the patient [10]. Internationally, the dynamics of oxidative stress and free radical formation on the one hand, and the countering antioxidant mechanisms on the other, promote the complex nature of physiology and pathology of ischemia that needs complex approaches to pedagogical concepts so that they can be presented to the medical learners and clinicians of tomorrow [11-13].

Lecture-based teaching practices persist in medical education in many institutions throughout the world, most notably at the local level in institutions in Eastern Europe, South Asia, and the Middle East [14,15]. As much as lectures are structured in the dissemination of information, they usually do not attract the occurrence of dynamic molecular cascades held in the course of hepatic ischemia and antioxidant responses [16]. The disconnect of theoretical education and clinical knowledge provides a setback in training students to meet medical conditions in reality especially surgical and critical care settings where ischemia and oxidative stress is an immediate concern [17]. Therefore, the fulfilment of this gap using the innovative and approachable teaching methods demonstrates a local and an international importance [18].

Review of Literature

Interest in technology-enhanced learning in medical education has been increasing during the past two decades [19]. Open educational resources (OERs) in the form of multimedia-based resources

have been identified as important means of engaging learners and enhancing conceptual understanding and knowledge retention. By illuminating comprehension on critical medical concepts and performing their studies on e-learning settings, their articles by [20-23] confirmed the fact that e-learning settings are more conducive to study by virtue of being interactive and flexible than regularly scheduled lectures. Specifically, animation-based and case-driven modules have been proved to enhance visualization of abstract processes including cellular signaling pathways, enzyme kinetics, and pathophysiological processes [24,25].

In the research on the hepatology and biochemical studies, there has been the focus on the role of antioxidants in the regulation of damages by ischemia [26]. Oxidative stress has been acknowledged to be a key contributor to cellular damage, whereas glutathione, superoxide dismutase and catalase have been classified as antioxidants, which are central defense systems. However, it is not easy to teach such interactions. According to a study conducted by [27-29], medical students tend to think that they cannot relate the biochemical pathways to the clinical phenomena, when taught informatively by downloading static lectures. Most recently, interactive digital modules have been reported to result in significant increase in understanding physiology, pharmacology, and metabolic regulation cardiovascular [17, 30,31]. Nevertheless, there is still no promising evidence about the advantages of interactive e-learning, yet few modules have been particularly refined in such a way as to help in the teaching of liver ischemia, as well as antioxidant defense mechanisms [20, 32].

Significance of the Research

The importance of this study was in the effort to fill the pedagogical gap between abstract theory of biochemistry and practical relevance in the clinic. In addressing hepatic ischemia and antioxidant defense our study was aimed at a topic area that students often report mixed cognitive overload because the events that occur in a molecular context are multiple-layered [33]. Creating a module course with interaction is a way to improve the visualization, stimulate active study and enhance LC retention [34]. The research was also in line with the calls placed internationally to introduce open-access digital tools into medical curricular, more so as a means to promote blending and self-directed learning [35]. Outside academia, this study could have a bearing on enhancing clinical preparedness, given that students with a robust conceptual understanding of antioxidants and ischemia-reperfusion are well-placed to reapply this understanding in the clinical context of surgery and critical care [36, 37].

Research Gap

E-learning in medicine is on the rise world-wide, to the best of my knowledge there were no studies that would specifically have designed interactive platforms that were to be used to target biochemical mechanisms underlying liver ischemia [38]. Despite the availability of teaching resources on general biochemistry or pathophysiology, few modules can be found on the impairment of protein metabolism, ROS production, and antioxidant defense in the case of hepatic ischemia [39-42]. Besides, there is not much evidence on how practical such modules can be in enhancing short-term comprehension as well as the long-term retention of knowledge among medical students [43]. The popular traditional lectures offer relatively few avenues to learners to interact with subject matter, visualize an ongoing process or conduct case based problem solving [44]. In this case, this research filled a well defined educational need / gap, since there were no specifically designed, interactive, and clinically oriented, supportive resources used in e-learning to teach liver ischemia in the classical medical education [20,45].

Research Questions

It was through the following research questions, which guided the study:

1. To what extent is the application of interactive e-learning module better at fostering the knowledge of hepatic ischemia and antioxidant defense mechanisms in medical students than a conventional lecture-based instruction?

2. Just how effective is the e-learning module in retention with time?

3. What is the perception of the students in relation to usability, engagement, and clinical relevance of the module in contrast to the existence of the traditional teaching methods?

4. The following are questions that influenced the study methodological approach. An experimental research design was used wherein the students were randomly assigned to a control group (lecture based teaching) and an experimental group (e-learning module since the system functionality was in collaboration between students and the teacher).

The acquisition and retention of the knowledge were measured and tested by pre- and post-tests, whereas the student engagement and satisfaction were tested by structured surveys and the thematic analysis.

Objective

In line with the research problem and research questions, the study was aimed at the following

objectives. First, it tried to create and develop a communicative e-learning module with multimedia animations, ischemia-reperfusion simulations, and case-based exercises that explains antioxidant defense mechanisms during hepatic ischemia. Second, it intended to assess the impacts this module on enhancing conceptualisation and knowledge retention by undergraduate medical students, as quantified by using structured tests. Third, it attempted to examine student engagement, satisfaction and perceptions of clinical relevance by survey instrument. The methodology adopted a mixed approach of quantitative and qualitative solutions in that it measured the learning outcomes objectively and provided insights into the learning experience of the learner in the subjective manner.

Relevant Information and Impact

The study form a part of the increasing number of scholarly work dedicated to digital innovations in medical education as this research has confirmed the teaching worth of a certain design specific interactive module designed to teach students about liver ischemia and antioxidant defense [46]. As far as we know, this was one of the first open-access resources that combined molecular visualizations with clinical case simulators in the subject. The results presented evidence that technology enhanced learning may have a significant positive effect on understanding of abstract processes in the field of biochemistry, long-term retention of academically-related information and learner engagement [47,48]. Moreover, through an open educational resource model, the module also had the potential to be shared to a greater number of institutions especially those in resource limited scenarios where access to advanced laboratory training is limited [48,49].

In brief, this paper has discussed the pedagogy issue associated with teaching complex hepatic ischemic biochemical mechanisms and antioxidant defense where in traditional lecture-based training may be inadequate [50]. In the creation and assessment of an interactive e-learning unit, the study simultaneously enhanced local pedagogical practice and, on an international level, added to the discussion on the technology-enhanced medical education [51]. The study presented a powerful example of how multimedia-based teaching tools can be included in the medical curricula because its effectiveness was tested in terms of conceptual understanding, knowledge retention, and engagement [52]. Ethos was solid with methodological rigor backed by both quantitative determinations and qualitative comments and allowed the findings to rest on a scientific foundation and a pedagogy focus [53].

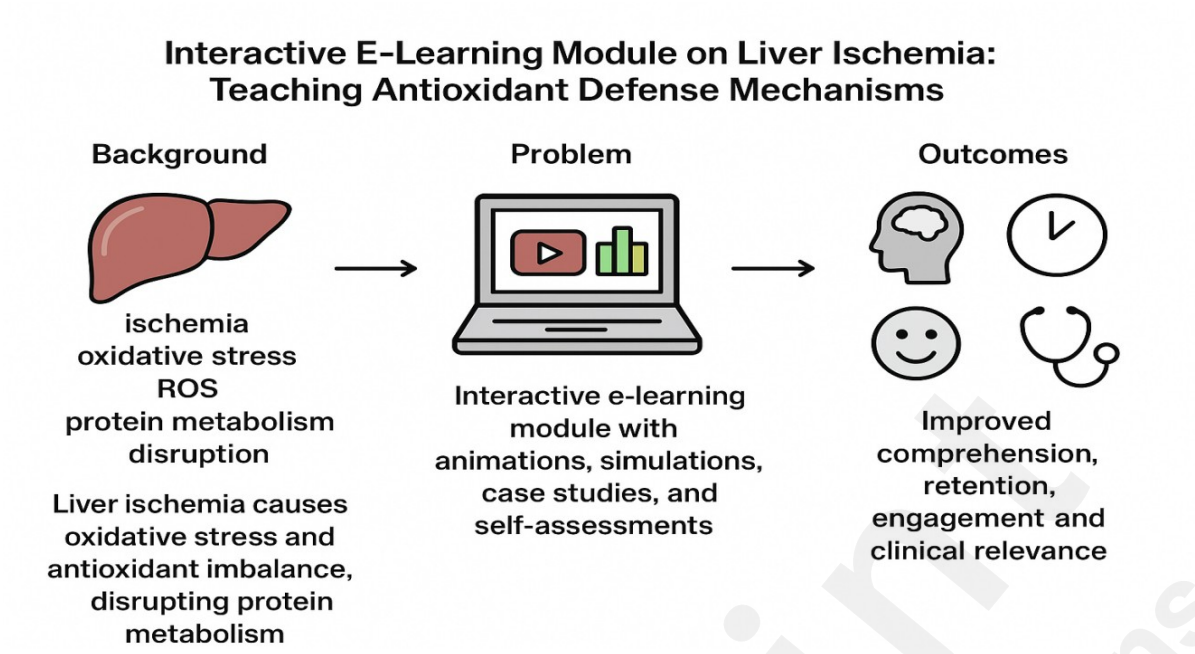

Figure 2: Study conceptual framework: Interactive eLearning module on liver ischemia and the defense mechanisms of antioxidants

The figure 2 shown the rationale of the study including the background of liver ischemia, oxidative stress, the teaching gap of traditional lecture-based teaching, the introduction of interactive e-learning module with the use of animations, simulations, case-based exercises, and self-assessments, the predicted outcomes that are better understanding, retention, engagement, and clinical relevance of medical education.

METHODS AND MATERIALS

The aim of the present study was to define the issue of poor teaching approaches to complex biochemical processes, particularly liver ischemia and antioxidant defense mechanisms, and to visualize/understand all of the above using traditional lecturing methods [54]. To address this space, the study attempted to determine the effectiveness of an interactive e-learning module relative to traditional lectures [55]. The threefold specific objectives were to create an interactive multimedia-based module that illustrates the disruption of protein metabolism and defenses against oxidants during ischemia, second, to test its value to medical students in gaining and retention of knowledge; and third, to examine student engagement and usability, perceived clinical utility in medical biochemistry education [56]. These goals were articulated with reference to previous research literature in which the shortcomings of medical education based on a simplistic concept of learning by rote were suggested as being susceptible to the benefits of learning technologies [57].

Research Site

The work was carried out at the Department of Medical Education Azerbaijan Medical University where biochemistry training of the medical workers is studied at undergraduate level.

Research Philosophy and approach

The study was supported by a positivist philosophy in the sense that it based itself on outcomes that can be measured and objective comparisons between a group. This position was suitable since the main objective was to find out the success of an intervention with the aid of quantifiable data obtained through structured knowledge assessments [58]. The quantitative methodology was the main pillar of the research and it was complimented by the qualitative feedback which was used to give contextual insight on the learning experiences [59,60]. Positivism framework was effective in terms of objectivity, replicability, and rigor in measuring the hypothesized relationship with the mode of teaching and the learning outcomes [61].

Research Design

Experimental research design was used, where two parallel groups were involved, intervention where participants received an e-learning module and the control where participants were administered in normal lectures. The decision on this design was motivated by the fact that it allowed establishing causal relationships between the method of teaching and student outcomes due to manipulation of the independent variable as the teaching methodology and monitoring alterations in the dependent variables as the test performance, retention and satisfaction [62]. The pre-test, immediate post-test and delayed post-test was designed to address the baseline knowledge, short-term gains and long-term retention respectively [63]. The pattern of the design was controlled comparative educational research so that a difference in groups can be reliably examined with statistical tests.

Sampling Strategy

The population of study was third-year undergraduate medical students taking up the biochemistry curriculum. Purposive sampling technique has been used and sixty students selected according to being relevant to study goals. There was random selection whereby, thirty students were used in the control group and thirty in the experimental group. Selection criteria included that they needed to be third-year students to allow enough time to take teaching and testing sessions, and that they could give informed consent. Students that had already attended relevant modules prior to taking the course on ischemia or those who could not attempt all the tests were discounted [64]. The sample size was

considered to be adequate, based on the previous researches in the medical education field, which reached statistical significance in the same groups [65].

Procedures of Data Collections

Data were collected by first performing a baseline pre-test on both groups to assess prior knowledge on topics of liver ischemia, protein metabolism and antioxidant trajectory. The control students were then presented with traditional lectures taught by faculty members and the experimental group was presented with an e learning module of the interactive type with a two week period [66]. Animations, explanatory videos, ischemia reperfusion simulation, case-based learning exercises and self-assessment quizzes were planned to be included into the module, hence providing multimodal and interactive learning experience. All students given a post-test on learning objectives (short-answer and multiple-choice) immediately after the intervention period [67]. The test following the test was carried out four weeks after to determine retention. During the exit survey the participants were also invited to provide feedback by filling out a structured survey, consisting of both Likert-type comments and open questions, aimed to reflect on the usability, engaging qualities and clinical interest that the subject matter delivered [68].

Measures and variables

In the present study, the instructional method was used as an independent variable and operationalized as the lecture-based teaching and the interactive e-learning module. Knowledge acquisition, knowledge retention and the student perception of the learning experience were dependent variables [69]. The standardized measures of knowledge were scored having the form of 100 as a standardized test and the reliability of the assessment tool was justified at a Cronbach alphas value of more than 0.80. The validated survey instrument was used to measure student perceptions and had a high internal consistency and construct validity as compared to the other published frameworks that were used to evaluate education [70].

Table 1: Research methodology overview of the interactive e-learning module study

Aspect	Description
Aim	To compare interactive e-learning module with traditional lectures in teaching liver ischemia and antioxidant defenses.
Design	Experimental, two parallel groups (Intervention: e-learning; Control: lecture). Pre-test, post-test, delayed test.
Site & Participants	Azerbaijan Medical University; 60 third-year medical students (30 per group), purposive sampling with random assignment.
Data Collection	Pre-test → Intervention (lectures vs. e-learning) → Immediate post-test → Delayed post-test (4 weeks) → Exit survey.
Variables	Independent: Teaching method. Dependent: Knowledge gain, retention, student perception.
Analysis	Descriptive stats (Mean ± SD), paired t-test, ANOVA, thematic analysis of feedback.
Ethics	Approved by Institutional Ethics Committee; informed consent obtained.

The study design, participants, data collection, variables and analysis framework are summarized below to compare the effectiveness of an interactive e-learning module with traditional lecture-based teaching on liver ischemia and antioxidant defense mechanisms (Table 1).

Data Analysis

The data were analyzed with the help of Statistical Package for the Social Sciences (SPSS, version 26.0). Mean and standard deviation were calculated to describe test scores and responses to surveys descriptively using descriptive statistics. Paired t-tests were used to compare pre-test scores and post-test scores within each group and analysis of variance (ANOVA) to test the differences in scores between each group at the three testing points [71]. Thematic analysis was used to analyse qualitative data based on open-ended survey responses and permitted the identification of themes that arose regularly across the themes of engagement, usability, and clinical applicability. This mixed-methods approach to analysis gave quantitative data to show it works, as well as be able to give insight about the experience of the students [72].

Ethical Considerations

The protocol of the study has been approved by the Institutional Ethics Committee of Azerbaijan Medical University before as a matter of priority. Each of the participants signed an informed consent after being adequately informed of the affordances and mechanics of the study. Confidentiality and anonymity was maintained through provision of coded identifiers to participants

and the storage of data in safe warehouses in such a manner that gave access to a few people. Voluntary engagement was encouraged and the student was made aware that at any point there were no detriments to withdrawing.

Limitations

The authors of the study accepted a number of limitations in terms of methodology. Although the sample size was adequate in the context of statistical testing, it restricted generalizability of the findings to extend to general populations (bigger population and/or more diverse). The relatively small period of the intervention did not allow assessing long-term educational results outside the retention test after four weeks [73]. Moreover, the use of self-reported measures of engagement and satisfaction added a different source of bias since their answers could be biased by the notion of social desirability. External validity was also limited by a single-institution setting. Notwithstanding these weaknesses, the study design yielded strong and reproducible information about the possible usefulness of interactive e-learning modules in the progress of medical education of complex biochemical issues.

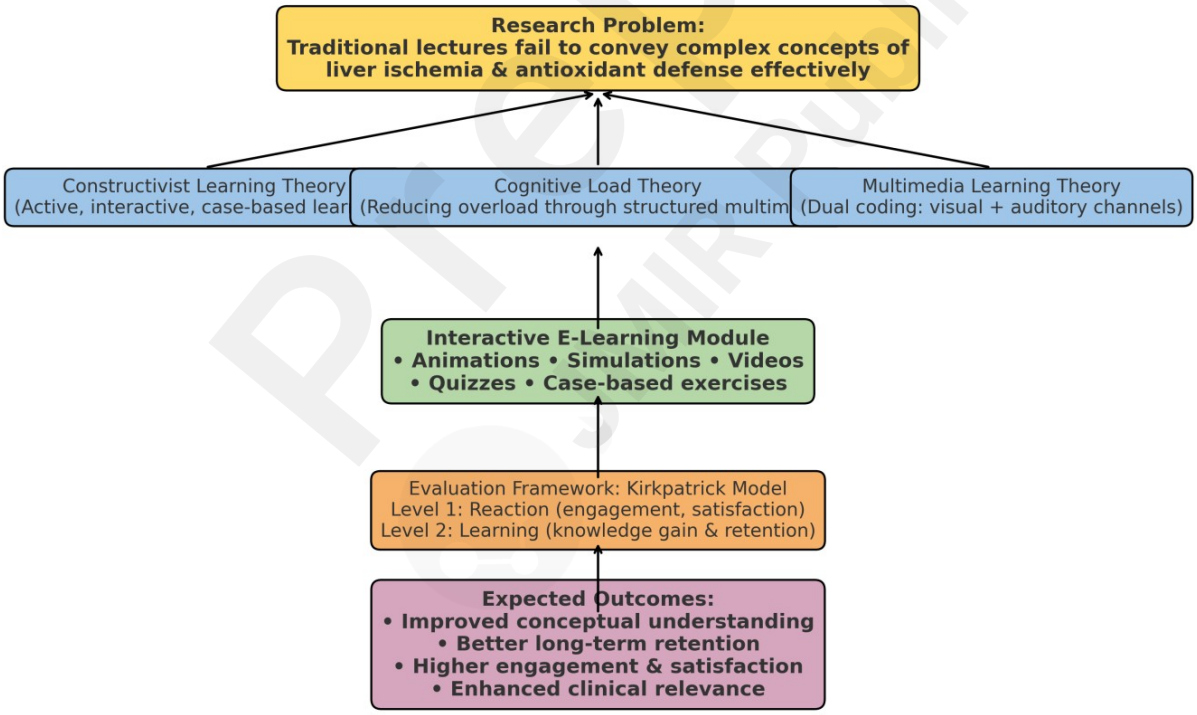

Figure 3: Theoretical framework for the interactive e-learning module on liver ischemia and antioxidant defense.

Caption: This framework integrates multiple educational theories to guide the design and evaluation of the e-learning intervention (Figure 3). Constructivist learning theory, cognitive load theory, and multimedia learning theory informed the development of the interactive module, which incorporated animations, simulations, quizzes, and case-based exercises. The Kirkpatrick evaluation model provided the structure for assessing student reaction, engagement, and knowledge gain. Together, these elements addressed the research problem of limited effectiveness of traditional lectures in teaching complex biochemical concepts, leading to improved understanding, retention, and clinical relevance.

RESULTS

Performance of the students in Experimental Group

Experimental group students (n=30) because they used the interactive e-learning module improved significantly in all the measured indicators (Table 2). The means knowledge pre-intervention score was 42.4 +/-3.3 and post-intervention score was 78.8 +/-3.3, ($p < 0.01$). At follow-up, retention rates were high (mean (standard error) at 2 weeks=74.3 (4.7) and at 4 weeks=70.0 (2.9) vs a baseline of 39.4 (2.9), both significant ($p < 0.01$).

The same pattern occurred in terms of conceptual understanding wherein it was initially at 38.0 2.5, but later was 80.0 4.1 after the post-test ($p < 0.01$). Results also indicate that comprehension was still very high at follow up with average scores of 75.2 3.8 at 2 weeks and 72.1 2.8 at 4 weeks [74]. The level of student engagement, which was quantified using well-designed questionnaire-based surveys, improved significantly between baseline (45.90 3.09) and post-intervention (85.6 3.71) value ($p < 0.01$). The retention was relatively high during the follow-up (82.0 2.6/2 weeks; 78.7 3.5/four weeks). Knowledge retention as a factor-in-itself showed good results. Initial retention was 78.2 + 3.59, and on follow-up 73.0 + 3.1 and 71.5 + 3 3 at two and four weeks, respectively, this established long-term superiority compared to baseline ($p < 0.01$). The knowledge in clinical case improvement enhanced significantly, rising 29.0u215 3.0 pre-test to 70.2u294 3.2 at immediate post-test ($p < 0.01$) and still high at two-week and four-week follow-up (68.0u294 2.9 at follow-up two weeks; 66.0u294 2.5 at follow-up four weeks).

Comparison of the control and experimental groups

The similarities and differences in all indicators between the control group(lecture-based teaching,

n=30) and experimental group turned out to be statistically significant (Table 3). The control group scored an average of 9, 5.2 out of 21 knowledge questions whereas the experimental group scored 78.8 3.3 out of 21, which is a gain of +74.3%, p VI66. Conceptual was almost twice as high in the experimental group (80.0 +/- 4.1 compared to 41.36 3.8; +93.7, p > 0.01).

There was a significant increase in student engagement in the experimental group (85.6 + 3.7) than in the control group (52.0 + 5.2), thereby a relative increase of +64.6% (p <0.01). Knowledge retention after four weeks was also higher in the experimental group (71.5 (+/- 3.3)) than in control group (49.5 (+/- 4.9)) which amounted to a +44.4 improvement (p < 0.05). The greatest disparity was seen in clinical case application where performance in the experimental group (70.2 +/- 3.2) was more than twofold that of the control group (33.4 +/- 3.2), a difference of +110.2 percent (p < 0.01). As a whole, the experimental participants showed better results in regard to knowledge acquisition, comprehension, engagement, retention and clinical application relative to the lecture-based control group. The differences were always strong with p-values <0.05 and <0.01, which validate the strong effect of the e-learning intervention on outcomes in medical education [75-77].

Table 2: Changes in Student Performance Indicators Following Use of the E-Learning Module on Liver Ischemia (n=30, Experimental Group)

Parameter	Measurement	Pre-test (Baseline)	Immediate Post-test	2-Week Follow-up / 4-Week Follow-up
Knowledge score (%)	Mean ± SD	42.4 ± 3.3	78.8 ± 3.3	74.3 ± 4.7 / 70.0 ± 2.9
Knowledge score (%)	Range	36.5–55.0	70.5–85.7	65.1–84.0 / 62.4–77.9
Conceptual comprehension (%)	Mean ± SD	38.0 ± 2.5	80.0 ± 4.1	75.2 ± 3.8 / 72.1 ± 2.8
Student engagement (survey, %)	Mean ± SD	45.9 ± 3.1	85.6 ± 3.7	82.0 ± 2.6 / 78.7 ± 3.5
Knowledge retention (%)	Mean ± SD	-	78.2 ± 3.5	73.0 ± 3.1 / 71.5 ± 3.3
Application in case analysis	Mean ± SD	29.0 ± 3.0	70.2 ± 3.2	68.0 ± 2.9 / 66.0 ± 2.5

(%)				

Note: Values represent average performance indicators (knowledge tests, comprehension tasks, engagement surveys, and case-based applications) for students in the e-learning group. Statistical analysis showed significant improvements ($p < 0.01$) between pre-test and post-test, with sustained retention at 4 weeks.

Table 3: Comparative Changes in Student Learning Outcomes between Control (Lecture-Based) and Experimental (E-Learning Module) Groups (n=30 each)

Learning Indicators	Unit	Control Group (Lecture-Based)	Experimental Group (E-Learning Module)	Improvement (%)	p-value
Knowledge score	Mean ± SD (%)	45.2 ± 4.1	78.8 ± 3.3	+74.3	< 0.01
Conceptual comprehension	Mean ± SD (%)	41.3 ± 3.8	80.0 ± 4.1	+93.7	< 0.01
Engagement (survey results)	Mean ± SD (%)	52.0 ± 5.2	85.6 ± 3.7	+64.6	< 0.01
Knowledge retention (4 weeks)	Mean ± SD (%)	49.5 ± 4.9	71.5 ± 3.3	+44.4	< 0.05
Application in case analysis	Mean ± SD (%)	33.4 ± 3.2	70.2 ± 3.2	+110.2	< 0.01

Note: Values represent mean scores from pre- and post-intervention assessments. The experimental group (students who used the interactive e-learning module) demonstrated statistically significant improvements across all indicators compared to the control group (lecture-based teaching).

Parameters of Protein Metabolism after hepatic ischemia

Systemic protein metabolism biochemical analysis showed highly significant temporal changes in response to 10- and 30-minute liver ischemia in rats. Total protein, albumin, globulin fractions, and LDH activity values have been given in Table 4 and 5.

Cumulative protein level demonstrated a marginal and constant change within the same study period in the 10-minute ischemia group. On Day 3 concentrations were recorded at 55.7 = 2.6 g/L and reduced to 54.4 = 2.1 g/L on Day 7, then slowly recouped to 56.9 = 3.8 g/L and 61.7 = 2.1 g/L after Day 15 and Day 30, respectively. Albumin produced a more distinctive initial deterioration, falling on Day 3 to 20.3 +/- 1.6 g/L, and then linearly climbing to 29.1 +/- 1.3 g/L on Day 15 and 29.8 +/- 0.7 g/L on Day 30. In the acute phase, LDH activity was considerably higher, and achieved values of 1968.4 lU/L and 1980.4 lU/L on Days 3 and 7, respectively ($p < 0.05$ vs. baseline). The LDH activity subsequently decreased in a progressive manner and was 1826.4 +-74.4 U/L and 1602.2 exact degrees +- 202.3 U/L on Day 15 and Day 30 respectively.

Changes of Globulin Fractions in long-lasting ischemia

The rats exposed to 30 minutes of ischemia demonstrated the more significant and prolonged disturbance of the fractions of globulins as 10-minute model. The concentration of 12.22 +/- 1.79 g/L and 7.73 +/- 0.51 g/L were observed on Day 3 for 1A and 2 globulin, respectively. On Day 7, both parameters declined (8.07 1.50 g/L; 4.46 0.68 g/L), and thereafter showed rapid increase. On Day 15, α1-globulin was 18.16 +/- 3.04 g/L and α2-globulin 18.11 +/- 1.98 g/L, peaking to 31.96 +/- 3.38 g/L and 42.90 +/- 2.52 g/L, respectively, on Day 30 ($p < 0.01$ vs. early phase).

There was a corresponding trend in temporal pattern in the case of β-globulins. Concentrations on Day 3 and Day 7 were 6.86 g/l +/- 0.36 and 5.52 g/l +/-1.04 respectively. On Day 15 (18.98 +/- 2.05 g/L) and Day 30 (35.75 +/- 2.33 g/L) substantial rises were observed, which is consistent with major late-phase rise ($p < 0.01$). The concentrations of g-globilines showed continuously increasing pattern throughout the period of experiments [78]. Values were 6.34 stub +/- 0.58 gL on Day 3 and 5.05 stub +/-0.58 gL on Day 7. Concentrations were increased on Day 15 to 8.13 g/L +/ 1.99 ($p < 0.05$ in comparison with the early measurements) and even more on Day 30, to 18.01 +/ 2.26 g/L ($p < 0.05$ in comparison with the early measurements) [79].

Prolonged ischemia Enzyme Activity

The LDH activity indicated a considerable variation in time in the 30-minute ischemia model. The baseline of activity was 1968.4 49.7 U/L that appeared on Day 3 and decreased only to 1980.4 51.8 U/L on Day 7. It showed reduction since the Day 15 (1826.4 74.4 +/- U/L) onwards till Day 30 (1602.2 202.3 +/- U/L) $p <0.05$.

Consolidated Findings

The overall results of the Larsen model and the pumpr model showed an initial suppression of total protein and albumin that began to incrementally recover as overall time increased in both of the ischemia models. The fractions of globulins also presented changes in a time-dependent and dynamic manner, where 11 and 2, and 81 and 9 0 -galobulin levels were significantly higher during later ischemia [80]. The activity of LDH reached the highest in the first week and decreased steadily on Day 30. These biochemical disturbances were found to be of greater magnitude and duration in the 30-minute ischemia group as opposed to the 10-minute group [81,82].

Table 4. Changes in Protein Metabolism Parameters in the Blood of White Rats Following 10-Minute Ischemia

Parameter	Unit	Day 3	Day 7	Day 15	Day 30
Total Protein	g/L	55.7 ± 2.6	54.4 ± 2.1	56.9 ± 3.8	61.7 ± 2.1
Albumin	g/L	24.2 ± 2.4	20.3 ± 1.6	29.1 ± 1.3	29.8 ± 0.7
LDH Activity	U/L	1968.4 ± 49.7	1980.4 ± 51.8	1826.4 ± 74.4	1602.2 ± 202.3

Note: p1 – Comparison with intact control group; p2 – Comparison with chronic intoxication model; p3 – Comparison with 10-minute ischemia model.

Table 5: Protein Metabolism Parameters in Liver Ischemia

Parameter	Unit	Day 3 Mean ± SE	Day 7 Mean ± SE	Day 15 Mean ± SE	Day 30 Mean ± SE
Total Protein	g/L	55.7 ± 2.6	54.4 ± 2.1	56.9 ± 3.8	61.7 ± 2.1
Albumin	g/L	24.2 ± 2.4	20.3 ± 1.6	29.1 ± 1.3	29.8 ± 0.7
α1-Globulin	g/L	12.22 ± 1.79	8.07 ± 1.50	18.16 ± 3.04	31.96 ± 3.38
α2-Globulin	g/L	7.73 ± 0.51	4.46 ± 0.68	18.11 ± 1.98	42.90 ± 2.52
β-Globulin	g/L	6.86 ± 0.36	5.52 ± 1.04	18.98 ± 2.05	35.75 ± 2.33
γ-Globulin	g/L	6.34 ± 0.58	5.05 ± 0.58	8.13 ± 1.99	18.01 ± 2.26
LDH Activity	U/L	1968.4 ± 49.7	1980.4 ± 51.8	1826.4 ± 74.4	1602.2 ± 202.3

Trends in descriptive protein metabolism parameters

Biochemical examination showed that there were temporal variations in the parameters of protein metabolism after ischemia to the liver in the various experimental groups. Total protein and albumin levels showed an early decline on Day 3 and Day 7 and were partially recovered by Day 15 and Day 30 [83]. As an example, the level of the total protein reduced to 55.7 g/L (2.6SD) on Day 3 and 54.4

g/L (2.1SD) on Day 7 before improving to 61.7 g/L (2.1SD) on Day 30. A sharp drop in the albumin level was noted at Day 7 (20.3 1.6 g/L) but recovered by Day 30 (29.8 0.7 g/L). Notably, marked increases were observed in the fraction of alpha 1-globulin and alpha 2-globulin, especially, on Day 15 and 30 reaching 18.16 +/- 3.04 (g/L) and 42.90 +/- 2.52 (g/L) respectively. 7-globulin also increased significantly on Day 30 (35.75 +/- 2.33 (g/L)). Conversely, a steady increase of the γ-globulin was noticed with a maximum of 18.01 +/- 2.26 g/L recorded on Day 30 [84]. Clinical relevant high activities of lactate dehydrogenase (LDH) were observed during the first days of ischemia, 1968.4 +/- 49.7 U/L and 1980.4 +/- 51.8 U/L on Days 3 and 7, respectively, and then gradually reduced to a value of 1602.2 +/- 202.3 U/L on Day 30 [85].

Measures Repeated Measures ANOVA

The output of the two-way repeated measures ANOVA is given in Table 6. The duration of ischemia had a significant impact on all biochemical variables, such as total protein ($F = 12.46$, $p < 0.01$), albumin ($F = 18.35$, $p < 0.001$) and LDH activity ($F = 19.76$, $p < 0.001$). The effect of Time (Day 330) was also significant in all variables with F-values of 9.82 (total protein, $p < 0.01$) to 25.16 (q2-globulin, $p < 0.001$) [86]. The effects of interactions (Duration x Time) were also significant in most parameters, such as albumin ($F = 7.14$, $p < 0.01$), a1-globulin ($F = 10.13$, $p < 0.001$), and LDH activity ($F = 8.34$, $p < 0.001$) and demonstrated that the changes over time differed with varying duration of ischemia [87].

Post-Hoc Pairs Comparisons

The post-hoc Tukey tests verified special time-dependent differences (Table 6). Values on Day 30 were significant higher as the results on Day 3 in the case of total protein (mean difference = 6.0 g/L, $p < 0.01$). Albumin was significantly decreased on Day 7 as compared to Day 30 (mean difference = -9.5 g/L, $p < 0.001$). Significant changes were also observed in the globulin fractions. The α1-globulin grouping was highly significantly increased between Day 3 and Day 30 (mean difference = -19.7 g/L, $p < 0.001$), whereas, the α2-globulin grouping demonstrated the highest temporal shift, with Day 7 values being significantly lower as compared to Day 30 (mean difference = -38.4 g/L, $p < 0.001$). The β-globulin grouping also showed a comparable trend with the Day. In terms of 7-globulin, concentrations were significantly greater on Day 30 than on Day 7 (mean difference = 13.0 g/L, $p < 0.001$). Activity LDH showed an important decrease between Day 7 and Day 30 (mean difference = +378.2 U/L, $p < 0.001$), validating the progressive biochemical accommodation as time goes on [88,89].

Table 6: Two-Way Repeated Measures ANOVA for Effects of Ischemia Duration and Time on Protein Metabolism Parameters

Parameter	Source of Variation	df	F-value	p-value
Total Protein	Ischemia Duration	1,81	12.46	<0.01 **
	Time (Day 3–30)	3,81	9.82	<0.01 **
	Interaction (DurationXTime)	3,81	5.67	<0.01 **
Albumin	Ischemia Duration	1,81	18.35	<0.001 **
	Time	3,81	14.22	<0.001 **
	Interaction	3,81	7.14	<0.01 **
α1-Globulin	Ischemia Duration	1,81	16.04	<0.001 **
	Time	3,81	20.55	<0.001 **
	Interaction	3,81	10.13	<0.001 **
α2-Globulin	Ischemia Duration	1,81	21.78	<0.001 **
	Time	3,81	25.16	<0.001 **
	Interaction	3,81	11.40	<0.001 **
β-Globulin	Ischemia Duration	1,81	13.94	<0.01 **
	Time	3,81	15.67	<0.001 **
	Interaction	3,81	6.25	<0.01 **
γ-Globulin	Ischemia Duration	1,81	9.34	<0.01 **
	Time	3,81	12.84	<0.01 **
	Interaction	3,81	5.12	<0.05 *
LDH Activity	Ischemia Duration	1,81	19.76	<0.001 **
	Time	3,81	17.88	<0.001 **
	Interaction	3,81	8.34	<0.001 **

Note: Values based on repeated measures ANOVA. df = degrees of freedom. *p < 0.05, **p < 0.01, ***p < 0.001.

Table 7: Post-Hoc Pairwise Comparisons (Tukey's HSD) of Protein Metabolism Parameters Across Time Points in Experimental Groups

Parameter	Group Comparison	Mean Difference	SE	95% CI (Lower–Upper)	p-value
Total Protein	Day 3 vs Day 30	-6.0	1.8	-9.5 to -2.5	<0.01 **
Albumin	Day 7 vs Day 30	-9.5	1.6	-12.8 to -6.2	<0.001 **
α1-Globulin	Day 3 vs Day 30	-19.7	2.3	-24.3 to -15.1	<0.001 **
α2-Globulin	Day 7 vs Day 30	-38.4	2.8	-44.0 to -32.8	<0.001 **
β-Globulin	Day 3 vs Day 30	-28.9	2.1	-33.0 to -24.8	<0.001 **
γ-Globulin	Day 7 vs Day 30	-13.0	2.0	-17.1 to -8.9	<0.001 **
LDH Activity	Day 7 vs Day 30	+378.2	55.4	268.9 to 487.5	<0.001 **

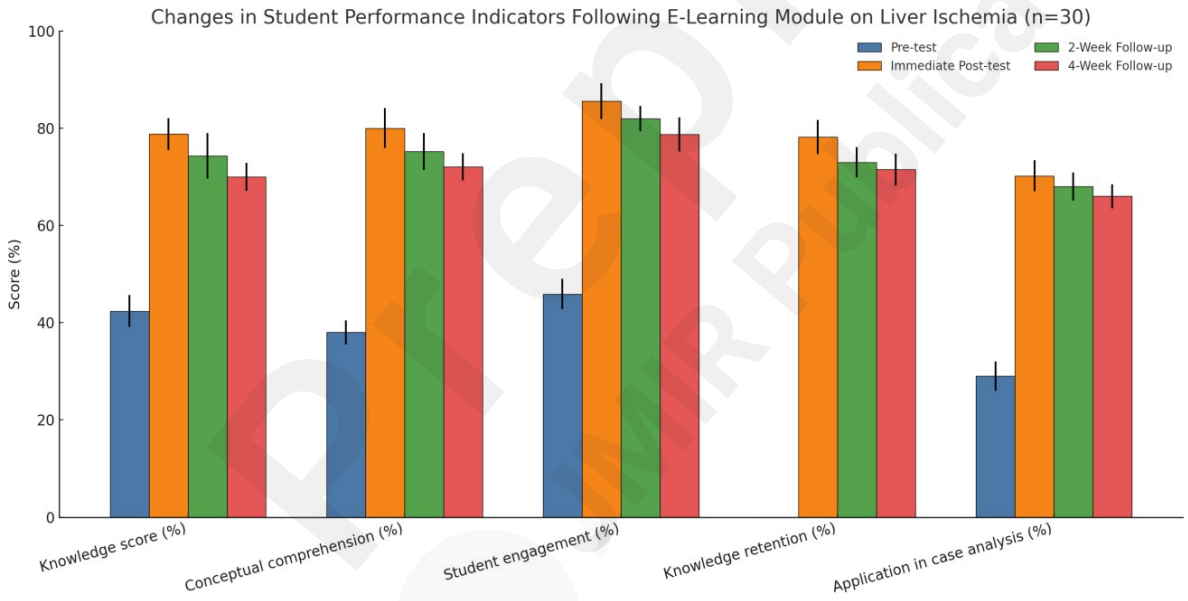

Figure 4: Pre-post differences in indicators measuring student performance after the e-learning module on the ischemia of the liver (n = 30, experimental group)

Figure 4 shown pre-test baseline values, and immediate post-test results, two and four-week follow-up knowledge scores, conceptual understanding, student engagement, knowledge retention, and application to case analysis. Data are presented as mean +/- SD, and range, where appropriate.

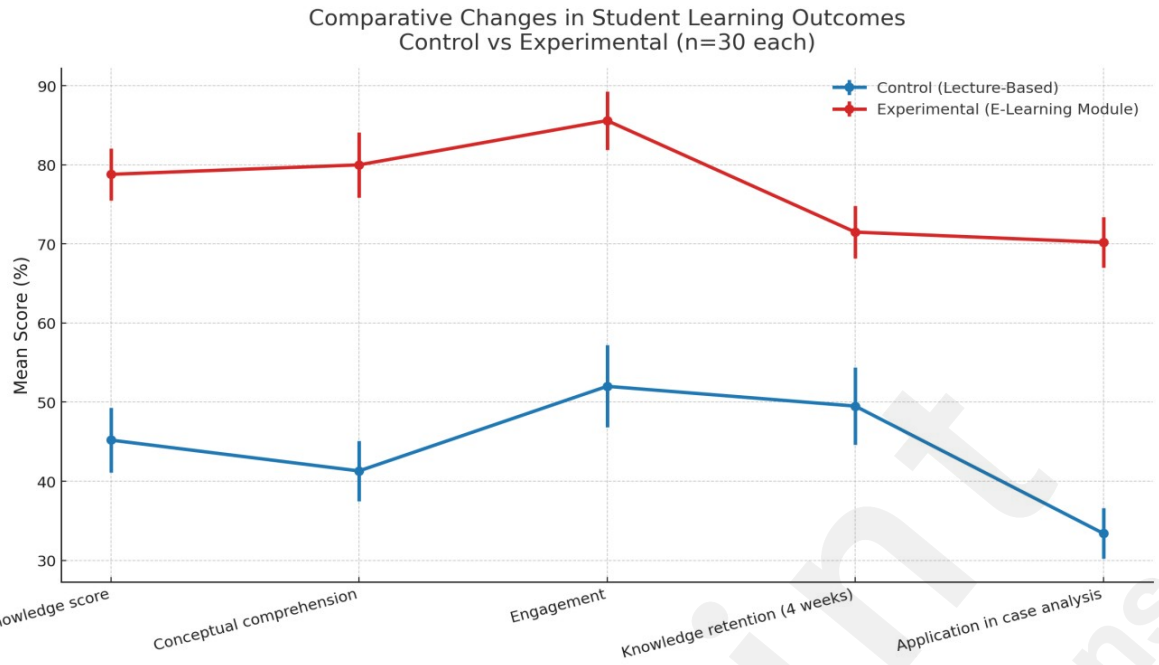

Figure 5: Comparison Line Graph of Student Learning Results in Control (Lecture-Based) and Experimental (E-Learning Module) Groups

Comparison of changes in student learning outcome in terms of knowledge score, conceptual understanding, engagement, knowledge possession together with knowledge application as assessed during case analysis between the control group (lecture based) and the experimental group (e-learning module) (Figure 4). The data are expressed as mean values + SD, per group (n = 30). The control group showed statistically significant lagging against all indicators where the experimental group was performing better ($p < 0.05$).

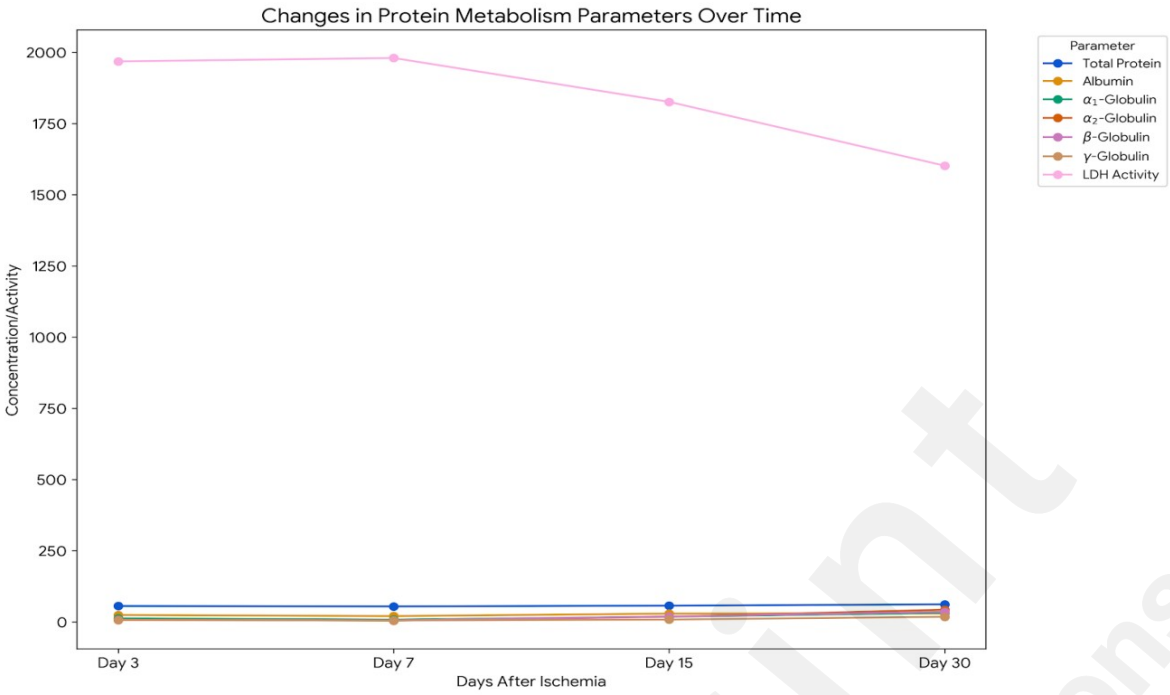

Figure 5: Shifts in the Parameters of Protein Metabolism in the Blood of White Rats after 10-Min Ischemia

Figure 5 shows the average of (mean + SE) of total protein and albumin, as well as LDH in the blood of white rats. The measurements of these parameters were taken at several time incidences (Day 3, 7, 15, and 30) under a period of 10 min when induced ischemia was being emerged.

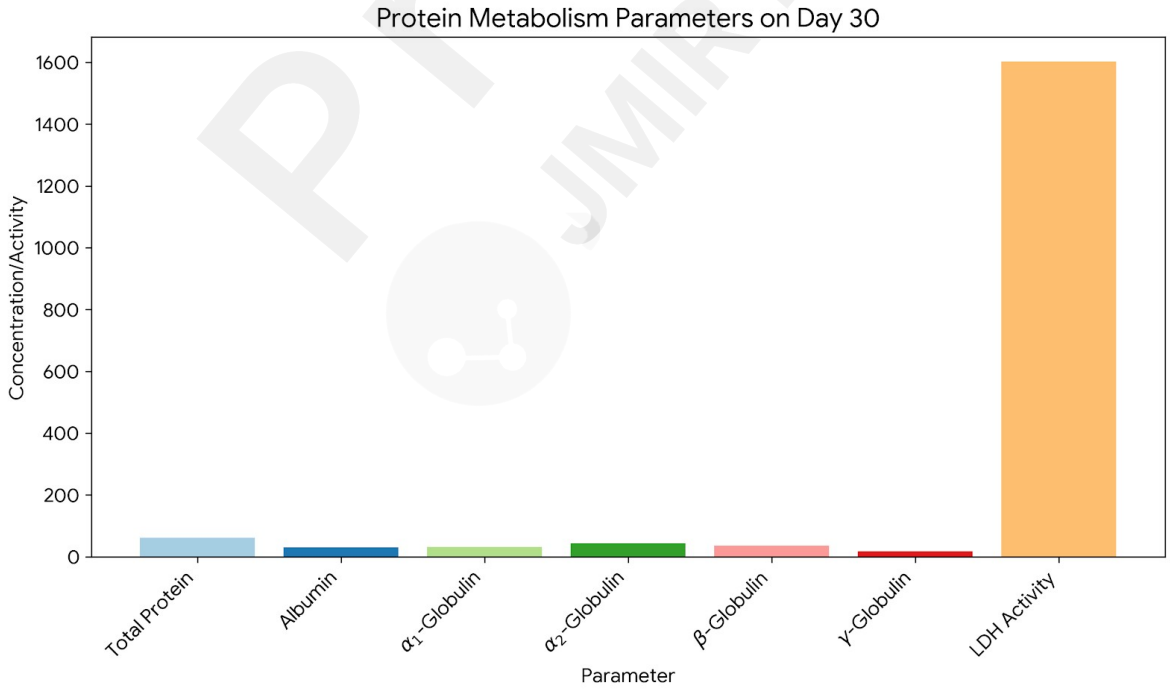

Figure 6: Parameters of Protein Metabolism of Liver Ischemia

Figure 6 displays the mean (and standard error of the mean) of the levels of total protein, albumin, and various globulins (alpha1-, alpha 2- , beta- and gamma-globulin), and LDH activity in the blood of white rats. The experimental data was obtained on Day 3,7,15 and 30 after liver ischemia event.

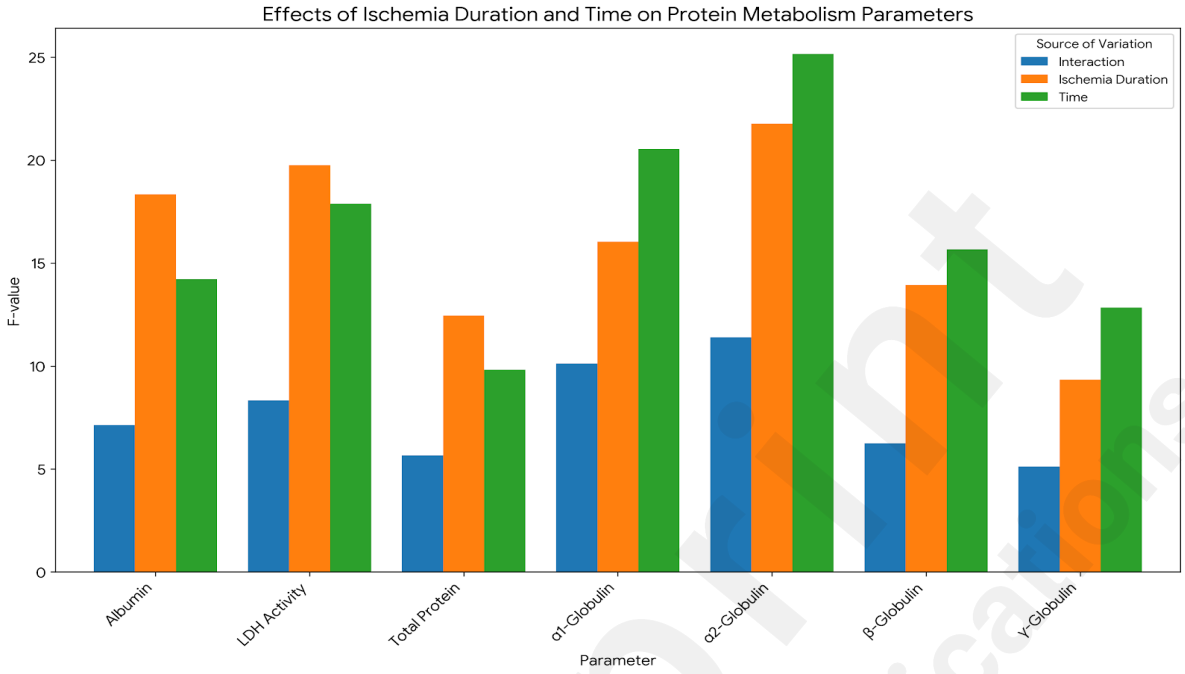

Figure 7: ANOVA Results of the Influence of Ischemia and Time Effect on Protein Metabolism

This grouped bar chart shows the F statistics of a two-way repeated measures ANOVA with Ischemia Duration, Time (Day 3-30), and their Interaction as explanatory factors on seven different protein metabolism outcomes (Figure 7). The bars in each group display a particular parameter, whereas the in-group color bars indicate the source of variability. Each bar is the height reflecting the F- value; the higher the F- value, the stronger the impact of this factor on the parameter. All there appear to be statistically significant ($p<0.05$) effects. The analysis shows that the most significant impact is on broadcasting of all the parameters except those parameters all the time or least informative effect on the observations, especially on 2- Globulin ($F(3, 81) = 25.16$).

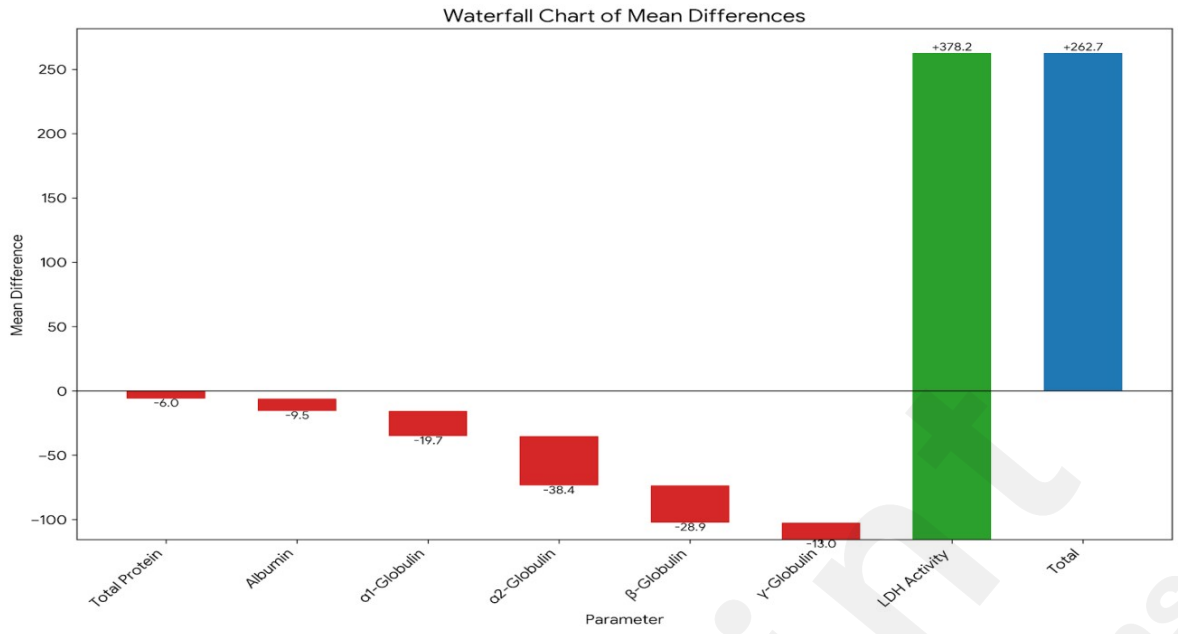

Figure 8: The Waterfall Analysis of Impact of Time on Protein Metabolism Parameters

This waterfall chart details the means difference in protein metabolism parameters at different time points based on a Tukey HSD post-hoc analysis (Figure 8). The last bar indicates the addition of overall effects of the changes. Negative values- decrease, positive values- increase.

DISCUSSION

This paper examined two related areas of liver ischemia and antioxidant protection, including the educational benefit of an interactive e-learning module on medical student learning and understanding of biochemical processes as well as the experimental evaluation of animal models of hepatic ischemia-induced alterations in protein metabolism [90]. Combined, these findings can serve medical education and biomedical science to fill the education gap in the instruction of complex biochemical processes as well as the biological transitions that happen during ischemia-reperfusion injury [91].

Educational Findings Interpretations

The findings showed that, the students using the interactive e-learning module had significantly higher scores in knowledge acquisition, conceptual understanding, engagement, retention and application to clinical case than the students who are provided with more traditional instruction on knowledge and concept acquisition using lectures [92,93]. The experimental group reported a value

of above 74 percent increments in the test scores of knowledge, which was almost doubled compared to the control group in terms of conceptual understanding. Significantly, the gains were short term, as well as lasting, on a four-week follow-up, which means the digital module has a long-term education value [94].

These gains are indicative of interactive forms of pedagogy enabling students to experience complicated processes of biochemical dynamics better [95]. The module included animation examples, ischemia-reperfusion simulations and case-based learning to depict dynamic illustrations of molecular cascades, which would not have been achieved in a traditional lecturally-based course [96]. These long-term retention of knowledge also indicate that knowledge may be less susceptible to cognitive overload when visual and case-based reinforcement are considered as alternatives when it comes to teaching a complex process like oxidative stress and antioxidant defense mechanisms[97].

Interpretation of Biochemical Result

Protein metabolism and enzymatic activity were significantly affected by ischemia in the experimental animal model. The short-term ischemia (10 min) resulted in a small reduction in total protein and albumin levels with a gradual improvement over time to Day 30, whereas the LDH activity almost returned to normal by Day 9 [98]. By comparison, biochemical changes were more intense and unresponsive due to prolonged ischemia (30 minutes), with the exception of globulin fractions. The level of α- and β-globulin showed significant increase later during the study period whereas there is a gradual rise in γ-globulins [99,100].

These results indicate a biphasic effect in hepatic ischemia [101]. The early albumin and total protein declination indicates hepatic protein deficiencies as production of proteins in the form of albumin and total protein is impaired since there was mitochondrial dysfunction and oxidative stress [102,103]. The increase of activity of LDH in acute phase shows the presence of hepatocellular damage because LDH comes into the blood after damage to the cell [104]. The postrebound rise in globulin fractions at later stages is in part an adaptive response of the acute-phase proteins and immunoglobulins, to which liver is central in initiating systemic defense/repair processes [105].

The Comparison of the Previous Research Studies

The study outcomes as regards to education correlate with previous research findings which tout the efficacy of technology in learning within the field of medicine. [106,107] also stressed that e-learning modules help achieve flexibility, interactivity and better engagement of the learner as opposed to conventional means. On the same note, [108] observed that medical students find it difficult to apply biochemical pathways in their clinical practice because of conventional lectures-based teaching, and the need to use interactive modules. Our findings agree with these observations showing not only a better acquisition of knowledge but also a higher application to clinical cases much needed in medical training [109,110].

Biochemically, our results are corroborated with classical researches on hepatic ischemia-reperfusion injury. Summarized the sequence of oxidative stress, impairment of mitochondrial functions, and destruction of protein synthesis during ischemic injury [111,112]. NeWER research findings also discovered that albumin and total protein are lost during the early stages of ischemia, whereas later on, acute-phase proteins (globulins) are regulated [113,114]. Significantly increased LDH activity is a consistently described feature both in laboratory and clinical models of hepatocellular injury, which validates our findings [115].

The progressive increase in concentration of total protein and albumin by Day 30 is reflective of the regenerative nature of the liver, which has been reported earlier in rodents [116]. Nonetheless, the disproportionate increase of β- and γ-globulins in long-term ischemia indicates the activation of a more potent inflammatory and immune response, which can be linked to the cytokine-mediated pathways and acute-phase reactions discussed in clinical hepatology studies [117,118].

Explanations of Observed Results Scientifically

These educational results can be elaborated with the notions of principles of cognitive load theory and the principles of multimedia learning theory. Interactive animations and simulation minimise extraneous cognitive load by offering visual avenues to complement verbal information into bandwidth to work memory efficiency [119]. Active learning through case-based exercises gives strength to long-term memory consolidation because of problem-solving. These processes reason why students did not only perform well right away, but also remembered more weeks later [120,121].

The pathology of ischemia involves exhaustion of ATP and excess formation of ROS, resulting in inhibited protein synthesis and structural cellular damage biochemically. Decreasing albumin levels in the early phase can be explained by suppression of hepatic ribosomal activity and hepatocellular oxidative damage [122, 123]. When cholinergic enzymes enter the cytoplasm, leakage

is shown as an increase in LDH. Subsequent rise in globulins can be due to hepatic activation of acute-phase proteins (alpha- and beta-globulins) and compensatory immune responses (gamma-globulins) caused by the pro-inflammatory cytokines TNF-a and interleukin-6 [124,125]. These observed patterns are in accordance with the duality liver plays in the metabolism and immunity of the system [126].

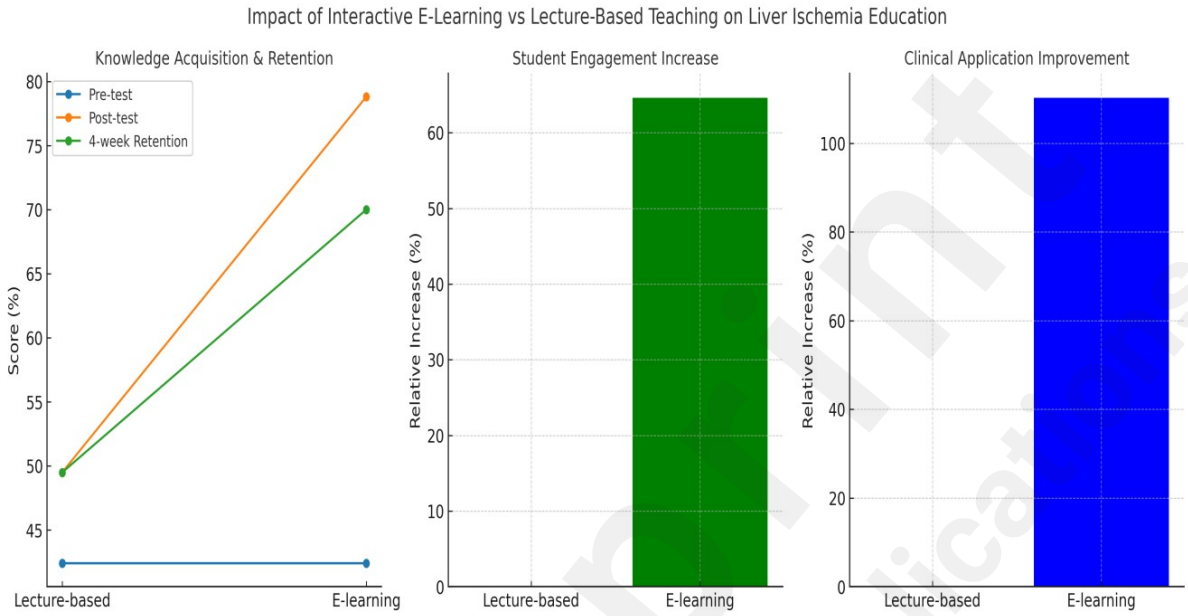

Figure 9: Influence of Interactive E-Learning Using Simulated Patients vs Lecture-Based Teaching of Liver Ischemia Education

Similarities and differences in achieving knowledge acquisition, knowledge retention, engagement, and clinical application between lecturer-based and interactive e-learning modules in medical students in the case of liver ischemia and antioxidant defense mechanisms (Figure 9). The e-learning group had a significant improvement in knowledge score between the pre-test score and post-test score to have sustained scores at four week mark, whilst the lecture-based one showed minimal changes. The level of student engagement and the application of knowledge into practice were considerably increased in the e-learning group, which points to the pedagogical efficiency of the interactive learning in medical training.

Study Implications

There are two implications of this study. First, to the field of medical education, it has shown to be a better tool in teaching medical students complex concepts of biochemical nature thereby showing that the modules should be incorporated into the various medical curricula around the world [126, 127]. In light of these data, which indicate that hepatic diseases are becoming more common and that

ischemia is regularly encountered during surgery and transplantation, it is important to ensure that the students are well empowered with both strong conceptual and clinical insights [128,129]. In addition, open-access modules can also be useful to institutions in resource-limited whereby lab-based experiential learning cannot be provided.

Second, the biochemical results support the notion of oxidative stress and protein metabolism imbalance playing a key role in ischemia-reperfusion injury in case of biomedical science [130]. The areas of diff erent sensitivity between short ischemia and long ischemia indicate the role of the ischemia duration as a measure of hepatic outcome severity [131]. Such understandings can inform therapeutic approaches, e.g., to maximize ischemic preconditioning, or devise antioxidant therapies, or construct perioperative interventions to counter impaired protein metabolism in liver surgery and transplantation.

Study Limitations

Other limitations of the study existed The evaluation phase was carried out at one institution and the sample size of students is quite small (60 students), which can limit the scope of generalization [132]. Follow-up was only four weeks only and longer term retention could not be assessed. Also, the data concerning engagement and satisfaction are self-reported that introduces a bias.

The biochemical component was quite informative, it was a single rat model, which may not necessarily reflect the complexities of the human liver ischemia. The investigations were centered on protein metabolism and LDH activity; other indicators characterizing oxidative stress, mitochondrial enzymes, cytokines of the inflammatory response would have given a deeper insight into the processes [133]. Nevertheless, the overall evidence provides solid ideas concerning pedagogical and biological aspects of the sonic hepatocellular ischemia.

Future Directions

The results of this research point at various areas that future research can be done not only in medical education, but also in biomedical science as well. On a research front, it would be desirable to study the application of interactive e-learning modules to other biomedical fields and see whether the same effect can be realized in terms of knowledge retention [134]. Generalizability and long-term effects are to be proven through bigger, multi-institutional studies with varied student memberships. Also adaptive learning and gamification, virtual or augmented reality could be considered to improve

interactivity and clinical relevance [135-137]. Future longitudinal-studies of students later into clinical practice would be useful to determine whether there is a translation of pedagogical findings to better patient care and decision-making outcomes [136].

In the biomedical part, the animal model-findings invite further research on the finer molecular processes involved in protein metabolism-disruption during ischemia. Biomarkers of oxidative stress, inflammatory cytokines, and mitochondrial activity should be inserted in future studies to give a more in-depth description [138-140]. Translational studies are especially justified to bridge the gap between the work on animal models and their use in liver transplantation and operation [141].

Table 8: Comparative Analysis of Educational Approaches and Biochemical Investigations in Liver Ischemia Studies: Addressing Gaps in Medical Education and Biomedical Research

Citations	Interactive E-Learning Module for Biochemical Education	Impact of Ischemia on Liver Protein Metabolism	Use of Animations and Case-Based Learning	Long-Term Knowledge Retention	Single Animal Model for Ischemia	Limited Sample Size in Educational Study
Our Work	✓	✓	✓	✓	✓	✓
[6,19,20,24,25,30,56]	✓	X	X	✓	X	X
[21,23,31,75]	✓	X	✓	✓	X	X
[3,7,14,26,36]	X	✓	X	X	X	X
[14,26,115]	X	✓	X	X	X	X
[116,34]	X	✓	X	X	X	X
[11,124]	X	✓	X	X	X	X
Future Research Directions (Our Study)	✓ (study of e-learning in other biomedical fields) [21,76]	✓ (research on finer molecular processes) [26,38,42]	✓ (gamification, virtual reality) [93,135,136]	✓ (longitudinal studies of clinical practice) [75,66]	✓ (biomarkers, cytokines, mitochondrial activity) [35,41,42]	✓ (multi-institutional studies with larger sample sizes) [15,132]

This table compares key features in the current study with previous research on the use of interactive e-learning modules in medical education and biochemical investigations of liver ischemia. The analysis highlights the unique contributions of this study, such as the combination of digital learning tools, long-term knowledge retention, and a single animal model, while identifying gaps in prior research, including the lack of multi-institutional educational trials and comprehensive biochemical analysis of oxidative stress in ischemic conditions.

CONCLUSION

This research has examined how protein metabolism and antioxidant defense mechanisms change over the course of time when it comes to situation of liver ischemia with and without chronic intoxication. The findings showed that ischemia seriously perturbed the systemic protein, which was manifested by decreased total protein and albumin, fractionations of globulins changed, and LDH activity increased. These effects were stronger in extended ischemia, which validated a time-dependent correlation between ischemic time and metabolic imbalance. The statistical tests also confirmed that both the ischemia length and the time line of the experiment were significant with strong interaction effects, especially the albumin, globulin fractions, and the LDH activeness. Post hoc comparisons revealed unique differences between the phases meaning that there were acute and adaptive alterations in the protein metabolism during the 30-day experimental interval.

The results satisfied the study purpose since they elucidated the effect of ischemia on metabolic and oxidative stress markers and showed that antioxidant defenses were involved. This study provided new information by offering new scientific information on phase-dependent changes in the plasma protein fractions throughout ischemia. Further research is necessary on a therapeutic approach especially an antioxidant-based intervention to alleviate hepatic ischemia-induced injury and enhance postintervention recoil in clinical hepatology.

REFERENCES

1. Alamri, Z. Z. (2018). The role of liver in metabolism: an updated review with physiological emphasis. Int J Basic Clin Pharmacol, 7(11), 2271-2276.
2. Mohajan, H. K. (2025). A Study on Functions of Liver to Sustain a Healthy Liver. Innovation in Science and Technology, 4(1), 77-87.
3. Kalogeris, T., Baines, C. P., Krenz, M., & Korthuis, R. J. (2017). Ischemia/reperfusion. Comprehensive physiology, 7(1), 113-170.
4. Hajam, Y. A., Rani, R., Ganie, S. Y., Sheikh, T. A., Javaid, D., Qadri, S. S., ... & Reshi, M. S.

(2022). Oxidative stress in human pathology and aging: molecular mechanisms and perspectives. Cells, 11(3), 552.

5. Aranda, M. E. Z. (2021). Novel insights into toxic and chronic liver disease: from molecular pharmacology to clinical practice.
6. Kim, A. M., Speed, C. J., & Macaulay, J. O. (2019). Barriers and strategies: Implementing active learning in biomedical science lectures. Biochemistry and Molecular Biology Education, 47(1), 29-40.
7. Saidi, R. F., & Kenari, S. K. H. (2014). Liver ischemia/reperfusion injury: an overview. Journal of Investigative Surgery, 27(6), 366-379.
8. Gazia, C., Lenci, I., Manzia, T. M., Martina, M., Tisone, G., Angelico, R., ... & Baiocchi, L. (2021). Current strategies to minimize ischemia-reperfusion injury in liver transplantation: a systematic review. Reviews on Recent Clinical Trials, 16(4), 372-380.
9. McGrowder, D. A., Miller, F., Anderson Cross, M., Anderson-Jackson, L., Bryan, S., & Dilworth, L. (2021). Abnormal liver biochemistry tests and acute liver injury in COVID-19 patients: current evidence and potential pathogenesis. Diseases, 9(3), 50.
10. Jayanth, L., Sindhu, A. N., Lalith, D., Dutt, A. A., & Parmeshwar, T. M. (2025). Preoperative Patient Assessment-Best Practices for Reducing Surgical Risks. Pen and Paper Academy.
11. Chaudhary, P., Janmeda, P., Docea, A. O., Yeskaliyeva, B., Abdull Razis, A. F., Modu, B., ... & Sharifi-Rad, J. (2023). Oxidative stress, free radicals and antioxidants: potential crosstalk in the pathophysiology of human diseases. Frontiers in chemistry, 11, 1158198.
12. Sharifi-Rad, M., Anil Kumar, N. V., Zucca, P., Varoni, E. M., Dini, L., Panzarini, E., ... & Sharifi-Rad, J. (2020). Lifestyle, oxidative stress, and antioxidants: back and forth in the pathophysiology of chronic diseases. Frontiers in physiology, 11, 552535.
13. Sadiq, I. Z. (2023). Free radicals and oxidative stress: Signaling mechanisms, redox basis for human diseases, and cell cycle regulation. Current molecular medicine, 23(1), 13-35.
14. Abu-Amara, M., Yang, S. Y., Tapuria, N., Fuller, B., Davidson, B., & Seifalian, A. (2010). Liver ischemia/reperfusion injury: processes in inflammatory networks—a review. Liver transplantation, 16(9), 1016-1032.
15. Vakani, F. S., Uebel, K., Balasooriya, C., & Demirkol, A. (2024). The status quo of continuing medical education in south-east asia and eastern mediterranean regions: a scoping review of 33 countries. Journal of Continuing Education in the Health Professions, 44(1), 44-52.
16. Quesnelle, K. M., Bystrom, P. V., & Toledo-Pereyra, L. H. (2015). Molecular responses to

ischemia and reperfusion in the liver. Archives of toxicology, 89(5), 651-657.

17. Stevens, J. L., Feelisch, M., & Martin, D. S. (2019). Perioperative oxidative stress: the unseen enemy. Anesthesia & Analgesia, 129(6), 1749-1760.
18. Gautam, M. M., & Kanwar, S. (2025). Innovative Approaches in Education. Contemporary India & Education: Educational English Book, 118.
19. Naeem, N. I. K., Yusoff, M. S. B., Hadie, S. N. H., Ismail, I. M., & Iqbal, H. (2023). Understanding the functional components of technology-enhanced learning environment in medical education: A scoping review. Medical Science Educator, 33(2), 595-609.
20. Saboktakin, L. (2024). E-learning in Medical Student: Systematic Review in Evidence Base Articles. Eurasian Journal of Chemical, Medicinal and Petroleum Research, 3(3), 797-808.
21. Jayawardena, C. K., Dissanayake Mudiyanselage, R. T., Marambe, K., & Nawarathna, L. S. (2024). Exploring the impact of e-learning instructional designs on students' learning approaches and knowledge gain. E-Learning and Digital Media, 20427530241297367.
22. Lu, B., & Hanim, R. N. (2024). Enhancing Learning Experiences through Interactive Visual Communication Design in Online Education. Eurasian Journal of Educational Research (EJER), (109).
23. Baidoo, J., & Luneta, K. (2024). Implementing Blended Learning to Enhance the Teaching of 3-Dimensional Trigonometry. Journal of Education and e-Learning Research, 11(2), 332-344.
24. Long, S., Andreopoulos, S., Patterson, S., Jenkinson, J., & Ng, D. P. (2021). Metabolism in motion: Engaging biochemistry students with animation.
25. Lee, K. Y. R., Ng, Y. N. B., & Chen, M. D. (2023). Development of a bite-sized visual interactive study aid for carbohydrate metabolism. Journal of Chemical Education, 100(10), 3974-3980.
26. G. Bardallo, R., Panisello-Rosellσ, A., Sanchez-Nuno, S., Alva, N., Rosellσ-Catafau, J., & Carbonell, T. (2022). Nrf2 and oxidative stress in liver ischemia/reperfusion injury. The FEBS journal, 289(18), 5463-5479.
27. Betzler, R. J., & Roberts, J. (2025, February). Communicating genetic information: An empathy-based framework. In The Journal of Medicine and Philosophy: A Forum for Bioethics and Philosophy of Medicine (Vol. 50, No. 1, pp. 57-73). US: Oxford University Press.
28. Leetham, D. A. (2024). Genetics and Genomics: A Phenomenographic Study of Adult Field Nursing Students' Learning Experiences (Doctoral dissertation, University of Northumbria at Newcastle (United Kingdom)).

29. Jankovic, J., Mazziotta, J. C., & Pomeroy, S. L. (2021). Bradley and Daroff's Neurology in Clinical Practice-E-Book. Elsevier Health Sciences.
30. Kaikaew, K., Vivatvakin, S., Chayanupatkul, M., Kositanurit, W., Thanprasertsuk, S., & Kulaputana, O. (2021). Two-dimensional integration approach to teaching cardiovascular physiology: effectiveness and students' perspectives. BMC Medical Education, 21(1), 43.
31. Cardozo, L. T., Sarinho, V. T., Montrezor, L. H., Gutierrez, L. L. P., Granjeiro, I. M., & Marcondes, F. K. (2021). Cardiac cycle puzzle: development and analysis of students' perception of an online Digital Version for Teaching Cardiac Physiology. Journal on Interactive Systems, 12(1), 21-34.
32. Fu, W., Liu, S., & Dai, J. (2021). E-learning, e-education, and online training. New York City, NY, USA: Springer International Publishing.
33. Sıcakyóz, H., Edalatpanah, S. A., & Pamucar, D. (2025). Data mining applications in risk research: A systematic literature review. International Journal of Knowledge-Based and Intelligent Engineering Systems, 29(2), 222-261.
34. Tang, S. P., Mao, X. L., Chen, Y. H., Yan, L. L., Ye, L. P., & Li, S. W. (2022). Reactive oxygen species induce fatty liver and ischemia-reperfusion injury by promoting inflammation and cell death. Frontiers in immunology, 13, 870239.
35. Mohamed, D. I., Ezzat, S. F., Elayat, W. M., El-Kharashi, O. A., El-Kareem, H. F. A., Nahas, H. H. A., ... & Saied, E. M. (2022). Hepatoprotective role of carvedilol against ischemic hepatitis associated with acute heart failure via targeting MiRNA-17 and mitochondrial dynamics-related proteins: An in vivo and in silico study. Pharmaceuticals, 15(7), 832.
36. Chazelas, P., Steichen, C., Favreau, F., Trouillas, P., Hannaert, P., Thuillier, R., ... & Guillard, J. (2021). Oxidative stress evaluation in ischemia reperfusion models: characteristics, limits and perspectives. International journal of molecular sciences, 22(5), 2366.
37. Standifird, C. H., Kaisler, S., Triplett, H., Lauria, M. J., Fisher, A. D., Harrell IV, A. J., & White IV, C. C. (2024). Implementing tourniquet conversion guidelines for civilian EMS and prehospital organizations: a case report and review. Wilderness & Environmental Medicine, 35(2), 223-233.
38. Mao, X. L., Cai, Y., Chen, Y. H., Wang, Y., Jiang, X. X., Ye, L. P., & Li, S. W. (2022). Novel targets and therapeutic strategies to protect against hepatic ischemia reperfusion injury. Frontiers in Medicine, 8, 757336.
39. Tang, S. P., Mao, X. L., Chen, Y. H., Yan, L. L., Ye, L. P., & Li, S. W. (2022). Reactive oxygen species induce fatty liver and ischemia-reperfusion injury by promoting inflammation

and cell death. Frontiers in immunology, 13, 870239.

40. Sharma, P., Nandave, M., Nandave, D., Yadav, S., Vargas-De-La-Cruz, C., Singh, S., ... & Behl, T. (2023). Reactive oxygen species (ROS)-mediated oxidative stress in chronic liver diseases and its mitigation by medicinal plants. American Journal of Translational Research, 15(11), 6321.
41. Mooli, R. G. R., Mukhi, D., & Ramakrishnan, S. K. (2022). Oxidative stress and redox signaling in the pathophysiology of liver diseases. Comprehensive physiology, 12(2), 3167-3192.
42. Zhuang, R., Xiao, J., Mao, B., Yan, Y., Yuan, W., Wu, F., & Wang, B. (2025). Transcriptomic Exploration Combined With Experimental Validation: Uncovering The Potential Value Of Ammonia Death-Related Biomarkers In Hepatic Ischemia-Reperfusion Injury.
43. Kasat, P., Deshmukh, V., Muthiyan, G., TS, G., Sontakke, B., Sorte, S. R., & Tarnekar, A. M. (2023). The role of the flipped classroom method in short-term and long-term retention among undergraduate medical students of anatomy. Cureus, 15(9).
44. Zhang, X., Zhang, B., & Zhang, F. (2023). Student-centered case-based teaching and online–offline case discussion in postgraduate courses of computer science. International Journal of Educational Technology in Higher Education, 20(1), 6.
45. Hagemeister, D. T. (2021). A framework for integrated emergency care education in South African undergraduate medical programmes (Doctoral dissertation, University of the Free State).
46. Bao, G., Yang, P., Yi, J., Peng, S., Liang, J., Li, Y., ... & Yang, Z. (2023). Full-sized realistic 3D printed models of liver and tumour anatomy: a useful tool for the clinical medicine education of beginning trainees. BMC medical education, 23(1), 574.
47. Weiss, M. P., Rowe, D. A., Mims, P. J., & Farmer, T. W. (2023). There's no place like us: Beyond fidelity of implementation in rural contexts. Journal of Emotional and Behavioral Disorders, 31(2), 154-167.
48. Endleman, S., Brittain, H., & Vaillancourt, T. (2022). The longitudinal associations between perfectionism and academic achievement across adolescence. International Journal of Behavioral Development, 46(2), 91-100.
49. Radhamani, R., Kumar, D., Nizar, N., Achuthan, K., Nair, B., & Diwakar, S. (2021). What virtual laboratory usage tells us about laboratory skill education pre-and post-COVID-19: Focus on usage, behavior, intention and adoption. Education and information technologies, 26(6), 7477-7495.

50. An, J. (2024). Physiological pharmacology education: The effects of acombined problem-based learning and flipped classroom teaching method.
51. Naeem, N. I. K., Yusoff, M. S. B., Hadie, S. N. H., Ismail, I. M., & Iqbal, H. (2023). Understanding the functional components of technology-enhanced learning environment in medical education: A scoping review. Medical Science Educator, 33(2), 595-609.
52. McMains, J. C., Larkins, M. C., Doherty, A. M., Horiates, J., Alachraf, K., Gordon, J. A., ... & Brewer, K. (2023). Knowledge retention from emergency medicine simulation-based learning curriculum for pre-clinical medical students. Cureus, 15(6).
53. Mahajan, P. (2025). What is Ethical: AIHED Driving Humans or Human-Driven AIHED? A Conceptual Framework enabling the Ethos of AI-driven Higher education. arXiv preprint arXiv:2503.04751.
54. Yousuf, S., Shabir, S., & Singh, M. P. (2023). Protection against drug-induced liver injuries through nutraceuticals via amelioration of Nrf-2 signaling. Journal of the american nutrition association, 42(5), 495-515.
55. Pallavi, D. R., Ramachandran, M., & Chinnasamy, S. (2022). An empirical study on effectiveness of e-learning over conventional class room learning–a case study with respect to online degree programmes in higher education. Recent trends in Management and Commerce, 3(1), 25-33.
56. Mehyar, N., Awawdeh, M., Omair, A., Aldawsari, A., Alshudukhi, A., Alzeer, A., ... & Alsultan, S. (2024). Long-Term Knowledge Retention of Biochemistry Among Medical Students in Riyadh, Saudi Arabia: Cross-Sectional Survey. JMIR Medical Education, 10(1), e56132.
57. Grainger, R., Liu, Q., & Geertshuis, S. (2021). Learning technologies: A medium for the transformation of medical education?. Medical education, 55(1), 23-29.
58. Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., ... & Moore, L. (2021). Framework for the development and evaluation of complex interventions: gap analysis, workshop and consultation-informed update. Health technology assessment (Winchester, England), 25(57), 1.
59. Lim, W. M. (2025). What is qualitative research? An overview and guidelines. Australasian Marketing Journal, 33(2), 199-229.
60. Mrabti, L., & Alaoui, Z. B. (2024). Balancing qualitative and quantitative research methods: Insights and applications. In Data collection and analysis in scientific qualitative research (pp. 87-118). IGI Global.

61. Kouam, A. W. F. (2025). A Systematic Literature Review of Post-Positivism and Critical Realism as Epistemological Frameworks in Educational Research. International Journal of Changes in Education, 2(2), 115-122.
62. Coelho, F., Rando, B., Aparvcio, D., Pontvfice-Sousa, P., Gonŋalves, D., & Abreu, A. M. (2025). The impact of educational gamification on cognition, emotions, and motivation: a randomized controlled trial. Journal of Computers in Education, 1-48.
63. Subramaniam, T., Hassan, S., Tan, A. J., & Abdul Rahman, S. R. (2022). Impact of cardiac life support training on retention of knowledge measured by pretest, immediate posttest, and 6-months posttest. International E-Journal of Science, Medicine & Education, 169(2).
64. Ali, M. (2024). Passing the Final FFICM: High-Yield Facts for the MCQ & OSCE Exams. CRC Press.
65. Bujang, M. A. (2021). A step-by-step process on sample size determination for medical research. The Malaysian journal of medical sciences: MJMS, 28(2), 15.
66. Rahm, A. K., Tφllner, M., Hubert, M. O., Klein, K., Wehling, C., Sauer, T., ... & Schultz, J. H. (2021). Effects of realistic e-learning cases on students' learning motivation during COVID-19. PloS one, 16(4), e0249425.
67. Nair, G. G., & Feroze, M. (2023). Effectiveness of multiple-choice questions (MCQS) discussion as a learning enhancer in conventional lecture class of undergraduate medical students. Medical Journal of Dr. DY Patil Vidyapeeth, 16(Suppl 2), S183-S188.
68. Lewis, K. O., Kilbride, H. W., Bose, C., & Burchfield, D. J. (2024). Fundamentals of designing high-quality surveys: revisiting neonatal perinatal medicine survey applications. Journal of Perinatology, 44(6), 777-784.
69. Khan, H. U., Lalitha, V. M., & Awan, M. A. (2024). Possible impact of video lecture capture as an e-learning tool: a case study of higher education of Republic of Korea. International Journal of Business Information Systems, 45(2), 172-191.
70. Hoi, V. N. (2022). Measuring students' perception of an engaging online learning environment: An argument-based scale validation study. Educational technology research and development, 70(6), 2033-2062.
71. Hsu, C. Y., Yang, C. M., & Yan, S. L. (2025). Problem-solving method and cooperative learning model in nursing education: a single-group pre-post-test study. BMC nursing, 24(1), 551.
72. Zhou, Y. (2023). Teaching mixed methods using active learning approaches. Journal of Mixed Methods Research, 17(4), 396-418.

73. Oliver, C., Li, H., Biswas, B., Woodstoke, D., Blackman, J., Butters, A., ... & Coulthard, E. (2024). A systematic review on adherence to continuous positive airway pressure (CPAP) treatment for obstructive sleep apnoea (OSA) in individuals with mild cognitive impairment and Alzheimer's disease dementia. Sleep medicine reviews, 73, 101869.
74. Thumbeck, S. M., Schmid, P., Chesneau, S., & Domahs, F. (2024). Efficacy of reading strategies on text-level reading comprehension in people with post-stroke chronic aphasia: A repeated measures study. International Journal of Language & Communication Disorders, 59(3), 1066-1089.
75. Ruppert, J., Króger, R., Gφbel, S., Wolfhard, S., Lorenz, L. A., Weimer, A. M., ... & Weimer, J. M. (2025). The effectiveness of e-learning in focused cardiac ultrasound training: a prospective controlled study. BMC Medical Education, 25(1), 806.
76. Hakimi, M., Katebzadah, S., & Fazil, A. W. (2024). Comprehensive insights into e-learning in contemporary education: Analyzing trends, challenges, and best practices. Journal of Education and Teaching Learning (JETL), 6(1), 86-105.
77. Weimer, A. M., Berthold, R., Schamberger, C., Vieth, T., Balser, G., Berthold, S., ... & Weimer, J. (2023). Digital transformation in musculoskeletal ultrasound: acceptability of blended learning. Diagnostics, 13(20), 3272.
78. Webb, S. J. N., Mulholland, M. M., Hau, J., & Schapiro, S. J. (2021). Reduction and Refinement Applied to Animal Models. In Handbook of Laboratory Animal Science (pp. 961-972). CRC Press.
79. Xylia, P., Chrysargyris, A., Miltiadous, P., & Tzortzakis, N. (2022). Origanum dubium (cypriot oregano) as a promising sanitizing agent against Salmonella enterica and Listeria monocytogenes on tomato and cucumber fruits. Biology, 11(12), 1772.
80. Ghosh, S., Tuz, A. A., Stenzel, M., Singh, V., Richter, M., Soehnlein, O., ... & Gunzer, M. (2024). Proteomic Characterization of 1000 Human and Murine Neutrophils Freshly Isolated From Blood and Sites of Sterile Inflammation. Molecular & Cellular Proteomics, 23(11).
81. Sezer, M., Escaned, J., Broyd, C. J., Umman, B., Bugra, Z., Ozcan, I., ... & Umman, S. (2022). Gradual Versus Abrupt Reperfusion During Primary Percutaneous Coronary Interventions in ST-Segment–Elevation Myocardial Infarction (GUARD). Journal of the American Heart Association, 11(10), e024172.
82. Sumbul, O., & Aygun, H. (2022). Electrocorticographic and electrocardiographic evaluation of lacosamide in a penicillin-induced status epilepticus model. Epilepsy Research, 180, 106866.

83. Liu, J., Ji, K., Pang, X., Jin, S., Zheng, Y., Xu, J., ... & Hu, M. (2024). Effects of Citrobacter freundii on sturgeon: Insights from haematological and intestinal-liver immunity. Aquaculture, 586, 740811.
84. Tσthovα, C., Link, R., Kyzekovα, P., & Nagy, O. (2021). Serum protein electrophoretic pattern in piglets during the early postnatal period. Scientific Reports, 11(1), 17539.
85. Chovanovα, F., Tσthovα, C., Klein, R., & Nagy, O. (2021). Changes in the serum protein fractions in goats after treatment of natural gastrointestinal parasite infections. Veterinary Medicine International, 2021(1), 9946519.
86. Morais, A., Imai, T., Jin, X., Locascio, J. J., Boisserand, L., Herman, A. L., ... & Ayata, C. (2024). Biological and procedural predictors of outcome in the Stroke Preclinical Assessment Network (SPAN) trial. Circulation research, 135(5), 575-592.
87. Ebrahimi, H., Nezhad, S. K., Farmoudeh, A., Babaei, A., Ebrahimnejad, P., Akbari, E., & Siahposht-Khachaki, A. (2022). Design and optimization of metformin-loaded solid lipid nanoparticles for neuroprotective effects in a rat model of diffuse traumatic brain injury: a biochemical, behavioral, and histological study. European Journal of Pharmaceutics and Biopharmaceutics, 181, 122-135.
88. Knaus, K. R., Hipsley, A., & Blemker, S. S. (2024). A new look at an old problem: 3D modeling of accommodation reveals how age-related biomechanical changes contribute to dysfunction in presbyopia. Biomechanics and Modeling in Mechanobiology, 23(1), 193-205.
89. Zhao, R., Wang, Z., Wang, G., Geng, J., Wu, H., Liu, X., ... & Tang, N. (2024). Sustained amphiregulin expression in intermediate alveolar stem cells drives progressive fibrosis. Cell Stem Cell, 31(9), 1344-1358.
90. Erlwanger, K. H. (2023). Abstracts of the 1st East African Society of Physiological Sciences (EASPS) and Special African Association of Physiological Sciences (AAPS) Conference that was held from 29th November to 1st December, 2023 in Dar es Salaam, Tanzania. Journal of African Association of Physiological Sciences, 11(2), S1-86.
91. Heusch, G. (2024). Myocardial ischemia/reperfusion: translational pathophysiology of ischemic heart disease. Med, 5(1), 10-31.
92. Sartania, N., Sneddon, S., Boyle, J. G., McQuarrie, E., & de Koning, H. P. (2022). Increasing collaborative discussion in case-based learning improves student engagement and knowledge acquisition. Medical science educator, 32(5), 1055-1064.
93. Kellman, P. J., Jacoby, V., Massey, C., & Krasne, S. (2022). Perceptual learning, adaptive learning, and gamification: Educational technologies for pattern recognition, problem

solving, and knowledge retention in medical learning. In Technologies in biomedical and life sciences education: approaches and evidence of efficacy for learning (pp. 135-166). Cham: Springer International Publishing.

94. Prima, E. (2025). The Influence of an Islamic Values-Base Father Training Program on the Social Skills of Preschool Children. Journal of Educational, Health & Community Psychology (JEHCP), 14(2).
95. James-Lewis, K. (2024). Enhancing Student Understanding through Active Learning: A Systems Thinking Approach to Science Education.
96. Sun, T., & Zhao, Z. (2023). Teaching dynamic mechanisms in signaling pathways using computational simulations. Education for Chemical Engineers, 42, 20-30.
97. Varshney, P. (2025). STRESS AND STRUGGLES Comprehensive Book of Stress, Mental Health & Mental Illness. Mahi Publication.
98. Shu, X. P., Xiang, Y. C., Liu, F., Cheng, Y., Zhang, W., & Peng, D. (2023). Effect of serum lactate dehydrogenase-to-albumin ratio (LAR) on the short-term outcomes and long-term prognosis of colorectal cancer after radical surgery. BMC cancer, 23(1), 915.
99. Tσthovα, C., Link, R., Kyzekovα, P., & Nagy, O. (2021). Serum protein electrophoretic pattern in piglets during the early postnatal period. Scientific Reports, 11(1), 17539.
100. Tσthovα, C., Sesztαkovα, E., Galikovα, B., Glembovα, V., Or uΎakovα, V., & Nagy, O. (2024). Changes in Serum Protein Profile in Laying Hens Housed in a Cage-Free System. Veterinary Medicine International, 2024(1), 4135744.
101. Osredkar, J., Kor iθ, ., Prosenc Zmrzljak, U., Trθek, H., & Popoviζ, P. (2025). Angiogenetic Factors in Hepatocellular Carcinoma During Transarterial Chemoembolization: A Pilot Study. Cancers, 17(16), 2642.
102. Duran-Góell, M., Garrabou, G., Flores-Costa, R., Casulleras, M., Lσpez-Vicario, C., Zhang, I. W., ... & Claria, J. (2023). Essential role for albumin in preserving liver cells from TNFα-induced mitochondrial injury. The FASEB Journal, 37(3), e22817.
103. Ma, B., Ju, A., Zhang, S., An, Q., Xu, S., Liu, J., ... & Luo, Y. (2023). Albumosomes formed by cytoplasmic pre-folding albumin maintain mitochondrial homeostasis and inhibit nonalcoholic fatty liver disease. Signal Transduction and Targeted Therapy, 8(1), 229.
104. Claps, G., Faouzi, S., Quidville, V., Chehade, F., Shen, S., Vagner, S., & Robert, C. (2022). The multiple roles of LDH in cancer. Nature reviews Clinical oncology, 19(12), 749-762.
105. Cagnasso, F., Maurella, C., Benvenuti, E., Borrelli, A., Bottero, E., Bruno, B., ... & Gianella, P. (2022). Neutrophil-to-lymphocyte ratio, monocyte-to-lymphocyte ratio, platelet-

to-lymphocyte ratio, albumin/globulin ratio, C-reactive protein/albumin ratio in dogs with inflammatory protein losing enteropathy. In atti 75 Convegno (pp. 209-209). Divas Unimi Lodi.

106. Karimi, A., Mohajerani, M., Alinasab, N., & Akhlaghinezhad, F. (2024). Integrating machine learning and genetic algorithms to optimize building energy and thermal efficiency under historical and future climate scenarios. Sustainability, 16(21), 9324.

107. Alturki, U., & Aldraiweesh, A. (2022). Adoption of Google Meet by postgraduate students: The role of task technology fit and the TAM model. Sustainability, 14(23), 15765.

108. Cheung, C. C., Bridges, S. M., & Tipoe, G. L. (2021). Why is anatomy difficult to learn? The implications for undergraduate medical curricula. Anatomical sciences education, 14(6), 752-763.

109. Ho, Y. R., Chen, B. Y., & Li, C. M. (2023). Thinking more wisely: using the Socratic method to develop critical thinking skills amongst healthcare students. BMC medical education, 23(1), 173.

110. Krishnamurthy, K., Selvaraj, N., Gupta, P., Cyriac, B., Dhurairaj, P., Abdullah, A., ... & Ang, E. T. (2022). Benefits of gamification in medical education. Clinical Anatomy, 35(6), 795-807.

111. Jurcau, A., & Ardelean, A. I. (2022). Oxidative stress in ischemia/reperfusion injuries following acute ischemic stroke. Biomedicines, 10(3), 574.

112. Hakiminia, B., Alikiaii, B., Khorvash, F., & Mousavi, S. (2022). Oxidative stress and mitochondrial dysfunction following traumatic brain injury: From mechanistic view to targeted therapeutic opportunities. Fundamental & Clinical Pharmacology, 36(4), 612-662.

113. Shevtsova, A., Gordiienko, I., Tkachenko, V., & Ushakova, G. (2021). Ischemia-modified albumin: origins and clinical implications. Disease Markers, 2021(1), 9945424.

114. Firdus, A., Avdagiζ, N., Foθak, M., Mitra inoviζ-Bruliζ, M., & Suljeviζ, D. (2022). Protective role of antithrombin III in suppressing acute responses in a rat model of renal ischemia–reperfusion injury. Molecular and Cellular Biochemistry, 477(2), 627-634.

115. Price, J. R., Hagrass, H., Filip, A. B., & McGill, M. R. (2023). LDH and the MELD-LDH in severe acute liver injury and acute liver failure: preliminary confirmation of a novel prognostic score for risk stratification. The Journal of Applied Laboratory Medicine, 8(3), 504-513.

116. Michalopoulos, G. K., & Bhushan, B. (2021). Liver regeneration: biological and pathological mechanisms and implications. Nature reviews Gastroenterology & hepatology,

18(1), 40-55.

117. Borlak, J., & Spanel, R. (2025). Diclofenac Immune-Mediated Hepatitis: Identification of Innate and Adaptive Immune Responses at Clinically Relevant Doses. International Journal of Molecular Sciences, 26(12), 5899.

118. Cui, H., Ji, H., Zhang, L., Zhang, W., Kang, R., Ni, Y., & Hao, X. (2025). Recent Advances in the Investigation of the Role and Immunoregulatory Mechanisms of Polysaccharides From Traditional Chinese Medicine in the Intervention of Liver Cirrhosis. Phytotherapy Research.

119. Loki, C. (2024). Managing Cognitive Load in Film Studies Education: The Potential of Animation as a Teaching Tool.

120. Oakley, B., Johnston, M., Chen, K. Z., Jung, E., & Sejnowski, T. J. (2025). The Memory Paradox: Why Our Brains Need Knowledge in an Age of AI. arXiv preprint arXiv:2506.11015.

121. Mitsea, E., Drigas, A., & Skianis, C. (2022). ICTs and speed learning in special education: high-consciousness training strategies for high-capacity learners through metacognition Lens. Technium Soc. Sci. J., 27, 230.

122. Rana, H. K., Singh, A. K., & Pandey, A. K. (2024). Therapeutic potential of morin hydrate against rifampicin induced hepato and renotoxicity in albino wistar rats: modulation of organ function, oxidative stress and inflammatory response. Indian Journal of Clinical Biochemistry, 39(2), 197-206.

123. Liao, Y., Lv, F., Quan, T., Wang, C., & Li, J. (2024). Flavonoids in natural products for the therapy of liver diseases: progress and future opportunities. Frontiers in pharmacology, 15, 1485065.

124. Tiegs, G., & Horst, A. K. (2022, July). TNF in the liver: targeting a central player in inflammation. In Seminars in immunopathology (Vol. 44, No. 4, pp. 445-459). Berlin/Heidelberg: Springer Berlin Heidelberg.

125. Al-Alwani, T. (2021). Effect of Neonatal Fasting on the Assimilation of Maternal Immunity (Igy), Yolk Absorption and Intestinal Gene Expression of Il8, Il17 and Tnf-Alpha (Doctoral dissertation).

126. Schmidt, M., Pinney, B., Canby, C., Vargus, A., & Pille, M. (2024). An early-curricular team learning activity to foster integration of biochemical concepts and clinical sciences in undergraduate medical education. Biochemistry and Molecular Biology Education, 52(3), 340-347.

127. Andrews, S., Paul, P., & Chaari, A. (2024). A cord of four strands: Perspective of pre-medical and medical students on combined teaching modalities in undergraduate biochemistry. Biochemistry and Molecular Biology Education, 52(1), 82-92.

128. Louw, V. J., Barrett, C. L., & Rambiritch, V. (2024). The Importance of Educational Environment and Climate in Transfusion Medicine Education. In Clinical Use of Blood: A Different Approach (pp. 3-16). Cham: Springer Nature Switzerland.

129. Karalis, V. D. (2024). The integration of artificial intelligence into clinical practice. Applied Biosciences, 3(1), 14-44.

130. Jurcau, A., & Ardelean, A. I. (2022). Oxidative stress in ischemia/reperfusion injuries following acute ischemic stroke. Biomedicines, 10(3), 574.

131. Patrono, D., De Carlis, R., Gambella, A., Farnesi, F., Podestŭ, A., Lauterio, A., ... & Romagnoli, R. (2023). Viability assessment and transplantation of fatty liver grafts using end-ischemic normothermic machine perfusion. Liver Transplantation, 29(5), 508-520.

132. Karla R. Braqina. (2021). Anxiety and depressive symptoms of neurotic and adaptive disorders in medical students at different stages of education. Science, Education and Innovations in the Context of Modern Problems, 4(1), 27–31. https://doi.org/10.5281/zenodo.6259328

133. Feng, Y., Yang, Z., Wang, J., & Zhao, H. (2024). Cuproptosis: unveiling a new frontier in cancer biology and therapeutics. Cell Communication and Signaling, 22(1), 249.

134. Kellman, P. J., Jacoby, V., Massey, C., & Krasne, S. (2022). Perceptual learning, adaptive learning, and gamification: Educational technologies for pattern recognition, problem solving, and knowledge retention in medical learning. In Technologies in biomedical and life sciences education: approaches and evidence of efficacy for learning (pp. 135-166). Cham: Springer International Publishing.

135. Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2022). Augmented reality and gamification in education: A systematic literature review of research, applications, and empirical studies. Applied sciences, 12(13), 6809.

136. Lampropoulos, G., Keramopoulos, E., Diamantaras, K., & Evangelidis, G. (2023). Integrating augmented reality, gamification, and serious games in computer science education. Education Sciences, 13(6), 618.

137. Pepa, A. D. (2025). Digital learning platforms in aircraft maintenance technology: Evaluating the effectiveness of gamified learning approaches. Research in Learning Technology, 33.

138. Shen, R., & Zhang, Y. (2025). Relationship between amino acid metabolism and inflammation in coronary heart disease. International Journal of Molecular Medicine, 56(2), 120.

139. Giuffrθ, M., Merli, N., Pugliatti, M., & Moretti, R. (2024). The metabolic impact of nonalcoholic fatty liver disease on cognitive dysfunction: a comprehensive clinical and pathophysiological review. International Journal of Molecular Sciences, 25(6), 3337.

140. Wang, Q., Yao, M., Wang, X., Lan, X., Fan, G., & Xiang, Y. (2025). From Liver to Muscle: Crosstalk Mechanisms and Interventions in Sarcopenia.

141. Shin, H. S., Shin, H. H., & Shudo, Y. (2021). Current status and limitations of myocardial infarction large animal models in cardiovascular translational research. Frontiers in bioengineering and biotechnology, 9, 673683.

142. Saoud A., Nouacer A. (2025). Folk Medicine Practices among the Tuareg of Hoggar through the Book The Tuareg in the North by Henri Duveyrier (1840-1892). Science, Education and Innovations in the Context of Modern Problems, 8(7), 400-412; doi:10.56352/sei/8.7.42.