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Integrating Research as An Educational Strategy to Weave Science into the Course Framework of Clinical Chemistry

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Abstract A prevalent belief is that research is exclusive for those pursuing advanced studies. The introduction of research-focused activities into clinical chemistry instruction is an initial measure to overcome this educational obstacle. The objective of this study is to intertwine science with educational content through a multidisciplinary approach. To achieve these goals, a carefully designed learning path and structured classroom instruction were used to deliver course content and engage students. The assignment included an introduction, evidence supporting the topic, an explanation of molecular-level mechanisms, and a conclusion. Student performance was evaluated including peer perception and teamwork in addition to the assay assignment using grading rubrics. The study found significant improvements in students' competence in research proficiencies after completing the project. This was particularly evident in their ability to comprehend complex molecular mechanisms using the experimental data found in the scholarly articles. Students demonstrated a solid understanding of the principles and theories related to the learning materials. Additionally collaborative efforts were successful, and peer-reviewed activities conducted by the students received positive ratings.

Keywords: *Upper-division undergraduate, clinical chemistry, course-based undergraduate research experiences, chemistry education, collaborative/cooperative learning, critical thinking*

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1. Introduction

Research activities are recognized as one of the high-impact educational experiences, extending beyond academic career goals and knowledge advancement. [1,2,3,4] They also contribute to the important aspects of the learning process. Course-based undergraduate research experiences (CUREs) are gaining attention as an effective way to engage students in doing research early in their college careers. CUREs offer several advantages over traditional courses and research internships. [3,4,5,6] They involve many undergraduates in science research at one time, and all students who enroll in a course are able to participate. The CUREs pedagogical approach has been utilized in many disciplines to enhance the quality of education. [6,7,8] This involves strategically applying current best practices to go beyond traditional academic boundaries and improve student learning outcomes.

Clinical chemistry education has undergone remarkable transformation over the years. The traditional emphasis has been on teaching technical competencies for application in clinical laboratory environments. There is little scholarly guidance for educators on how to weave research components into clinical chemistry curricula. A prevalent belief is that research is exclusive for those pursuing advanced studies. Evidence suggests that engaging students in the research-based course curriculum demonstrated greater academic growth compared to peers in the traditional teaching methods in various fields. [3] The introduction of research-focused activities into clinical chemistry instruction is an initial measure to overcome this educational obstacle. In this study, an effort was made to intertwine the research component into the clinical chemistry curriculum as an initial step to address this educational barrier.

The research activities implemented in the clinical chemistry course curriculum are shown in Figure 1. Our collaborative research project focused on an in-depth investigation of temozolomide (TMZ), a chemotherapeutic agent widely used in cancer treatment. This project was designed to enhance our understanding of how TMZ exerts its therapeutic effects and how histone post-translational modification is associated with epigenic regulation in disease process, especially in cancer cells. [9,10,11,12] Students are required to conduct literature research and collaborate to write an essay. They are encouraged to create their own data tables, graphs, and pictures to deepen their comprehension of these topics and develop critical thinking skills.

A structured outline was developed to align with the learning objectives ensuring a thorough and systematic exploration of the research topics. Assessment procedures were provided as guidance for students completing the project. The goal is to integrate the scientific component into the clinical chemistry course curriculum and foster critical skills through project design, literature review, data analysis, and effective scientific communication. Throughout this journey, students will not only gain valuable insights into the complexities of the scientific subjects but also improve their abilities to collaborate effectively, think critically, and present scientific findings accurately.

2. Methods

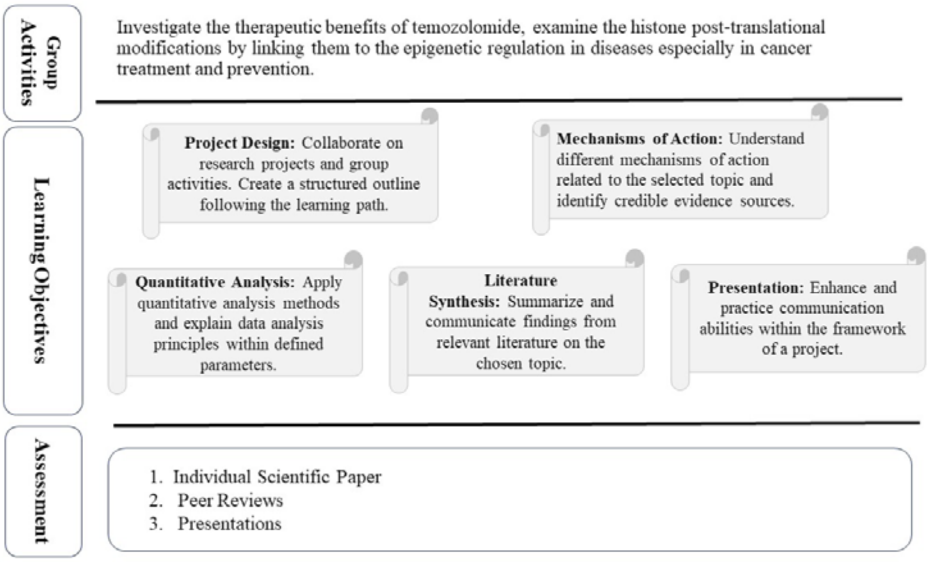

Figure 1. Overview of the implemented course activities with learning objectives and assessment

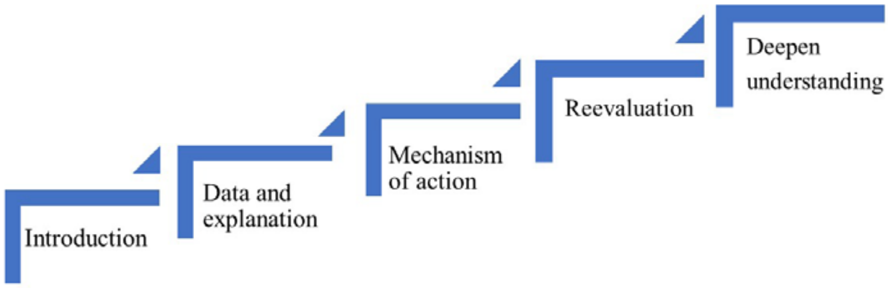

Figure 2. Project learning path

Pedagogical approaches: The key elements in the pedagogical approach in this specific teaching effort involves the following points:

1. **Project-based learning**: The teaching approach centers around an integrated research-based project, which allows students to tackle real-world problems. This project-based learning approach encourages active learning, problem-solving skills, and the practical application of theoretical concepts.
2. **Peer-to-peer support**: the project fosters peer-to-peer support, creating a collaborative learning environment where students can learn from and support each other.
3. **Structured classroom instructions**: It is a conscious effort to design instructions to ensure all students receive equitable guidance, promote a diverse and welcoming environment. The structured classroom instructions help to address these issues.
4. **Critical thinking and research activities**: The project focuses on understanding complex mechanisms of actions. This approach encourages critical thinking, analysis, and research skills, as students explore these topics in depth.
5. **Scaffolded learning path**: The learning path was designed to guide students through the process of understanding the topic. This scaffolded approach breaks down the learning process into manageable steps.

Overall, the pedagogical approach combines project-based learning, collaborative learning, inclusivity, critical thinking, research skills, and a scaffolded learning path. This entire approach aims to create an engaging and supportive learning environment that fosters deep understanding, problem-solving skills, and a sense of belonging for all students. The learning path which consists of five carefully segmented steps is shown in Figure 2.

Step 1. Introduction: begin with a conceptual overview

Step 2. Data and explanation: Explore relevant data and provide explanations.

Step 3. Mechanism of action exploration: Investigate the mechanism how it works.

Step 4. Reevaluation: Reconsider the initial explanation and mechanism of action

Step 5. Deepen understanding: Delve deeper understanding into the topic.

The multi-week project or assignment for the research project are outlined in Table 1. Each row represents a different week, with columns specifying plans, steps, and detailed instructions. The importance of this pedagogical approach is that it provides a structured framework and timeline for students to follow. It breaks down the overall project into smaller, manageable tasks and milestones, making it easier for the students to organize their work effectively and stay on track. Overall, this structured project instruction serves as a valuable resource for students, helps them navigate through the different stages of the project effectively and foster deep understanding, problem-solving skills, and a sense of belonging.

Table 1. Structured project instruction

Week	Plan	Instruction
Week 1	Topic Selection and Role Definition	Students are expected to select a topic, identify the connection between two factors through literature analysis, and define roles for each team member. This initial stage sets the foundation for the entire project.
Week 2	Drafting the paper	-**Introduction:** Explain concept, terminology, and knowledge specific to the selected topic. Focus on important principle and concept discussed in the project. -**Evidence to support the topic:** Present evidence of connection using graphs, excel charts or other plots from the literature in order to convince people there is a connection mentioned in your project. The data can be statistical analysis and experiment results from literature. All data provided need data table and graphic plots. Students are encouraged to create data tables or graphs if not available in the literature. - **Mechanism at molecular levels::** Use flow charts or images to explain how the connection works at molecular levels. -**Conclusion**: Summarize results. Discuss the problems and the future directions.
Week 3	Revised Draft	- dedicated to revising the draft based on feedback received in class, which is crucial for enhancing student learning and improving the quality of the project.
Week 4	Final draft	- further revisions and finalizing the draft based on additional feedback. Complete the final version of the paper.
Week 5	Presentation	- create a PowerPoint presentation to explain their project in class, incorporating pictures, tables, and graphs for a more engaging and visual representation of their work.

Table 2. Grading Rubrics for the proposed project

Sections	Rubrics
Introduction	Presented a precise understanding of the project following the outline. Used equations, figures, and graphs to explain the concept without errors or misspellings. Gradation based on the number of missing pieces of information (e.g., concept, equation, figure).
Data and Evidence	Demonstrated a strong and convincing evident based on the scientific results. Gradation based on the completeness of results, including title, axes, key findings, and explanations.
Molecular Basis Illustration	Provided a detailed molecular-level picture supporting the topic. Gradation based on completeness (title, axes, key results, and explanations).
Presentation	Excellent delivery with a well-prepared, engaging story and 80% graphic design. Gradation based on delivery quality and graphic design utilization.
Conclusion	Summarize the results obtained from data and mechanism of action at molecular level. The results and challenges are clearly linked to the materials and reflect a certain intellectual depth. Gradation based on accuracy of the statement and concise information from the results
Teamwork	The group demonstrates high cohesion with well-defined roles. Gradation is based on the overall quality of the project and roles for each section played by the students. Pays attention to details and ensures high-quality output.

Evaluation: To assess the effectiveness of the project and student performance, a comprehensive evaluation was conducted. This evaluation utilized a multi-faceted approach based on the grading rubrics outlined in Table 2. Students' understanding and presentation of the project were evaluated using the Introduction rubric. This assessed their ability to present a precise understanding of the project, use equations, figures, and graphs to explain concepts without errors, and adhere to the prescribed outline. The completeness of the introduction was graded based on the inclusion of key elements such as concept explanation, equations, and figures. The data and evidence rubric was used to evaluate students' ability to demonstrate a strong and convincing link to the topic selected. Gradation was based on the completeness of results, including appropriate titles, axes, key findings, and explanations. The Molecular Basis Illustration rubric assessed students' capacity to provide a detailed molecular-level picture supporting their topics. Like the data and evidence rubric, grading was based on the completeness of the illustration, including titles, axes, key results, and explanations. Presentation skills were evaluated using the peer perceived evaluation, which focused on the quality of delivery, storytelling, and the use of graphic design. Students were expected to deliver an engaging presentation with at least 80% graphic design utilization. The Teamwork rubric was used to assess group cohesion and the definition of roles within the team. Grading was based on the overall quality of the project and the roles played by each student in different sections. Finally, the literature synthesis is assessed using conclusion grading rubric, evaluated students' ability to summarize the results and link challenges to the materials, and propose future directions focused on improving current results.

The analysis included 42 students in 3 groups, assessing changes in these perceived research projects. Statistical tests (Wilcoxon Signed Ranks and Mann Whitney-U tests) were used to compare pre- and post-project completion competence. [13,14] Significance was considered at a p-value smaller than 0.01. Additionally, student-perceived peer evaluations were analyzed using a descriptive statistical analysis. This evaluation approach allowed for the assessment of student performance, project effectiveness, and the development of research skills throughout the course of the project.

3. Results

Based on the selected topics, the projects are separated into three sections:

Section 1. Mechanism of treatment studies

- Efficacy of Temozolomid in the treatment of glioblastoma using chronotherapy –
- The relationship between histone methyltransfease MMSET and DNA repair
- Y641 EZH2 mutation increasing trimethylation of site H3K27, leading to decreased tumor suppressor gene BLIMP1 expression in diffuse large B-cell lymphoma.
- Efficacy of temozolomide in treating glioblastoma multiforme
- Temozolomide increases the survival rate of brain cancer.

Section 2. Combination therapy

- Enhanced efficacy of temozolomide in treating glioma cells through EpoR silencing-
- Combination therapy of temozolomide and levetiracetam in glioblastoma
- Enhancing efficacy of treatment of glioblastoma through temozolomide and Doxorubicin combination therapy
- Enhanced survival in brain cancer patients using TMZ and radiation combination therapy.

Section 3. Histone acetylation

- Histone acetylation and gene expression regulation
- The connection between histone acetylation and histone deacetylase
- Role of histone acetylation in atherosclerosis in human carotid plaques

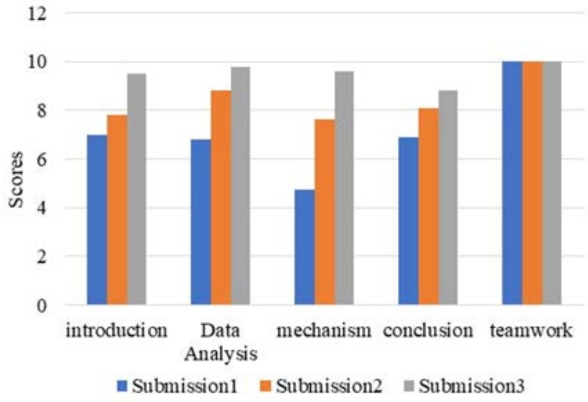

Figure 3. Average results among all students during the progression phase of the projects

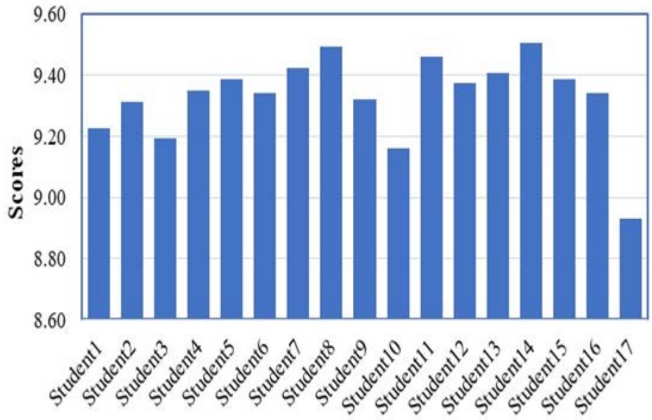

Figure 4. Average scores of peer reviewed results for each student in group1

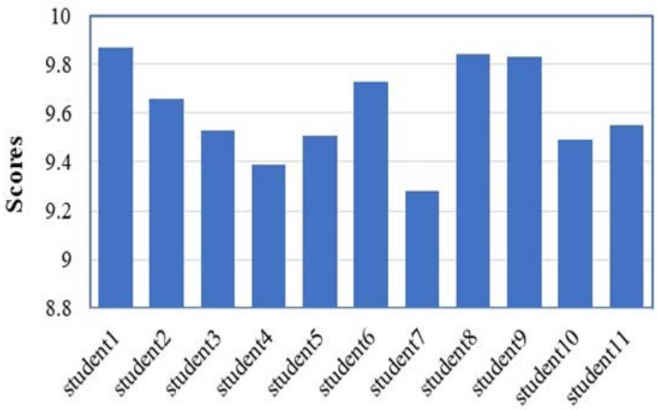

Figure 5. Average scores of peer reviewed results for each student in group 2

Table 3. Average results among all students during the progression phase of the projects

	submission1	submission2	submission3
Introduction	7	7.8	9.5
Data Analysis	6.8	8.8	9.8
Mechanism	4.8	7.6	9.6
Conclusion	6.9	8.1	8.8
Teamwork	10	10	10

Table 4. Statistical analysis of the learning outcomes before and post completion of the project

	Pre-		Post		P			
	Average	Range	Average	Range	P-Value	Improved(n)	No Change (n)	Decrease(n)
Introduction	7.0(6,8)	6 - 8	9.5 (8, 10)	8.0 - 10	0.00243	12	0	0
Mechanism of action	4.8(0,8)	0 - 9	9.6 (9,10)	8.0 - 10	0.00243	11	1	0
Quantitative analysis	6.8(0,9)	0 - 9	9.8 (8,10)	9.0 - 10	0.00368	12	0	0
Literature synthesis	6.9(0,8)	0 - 8	8.8(8,10)	8.0 - 10	0.00218	12	0	0

Competency assessed on a scale of 1 to 10 with 1 representing the lowest level of competency and 10 the highest. *P* obtained from Man U Test comparing pre- and post-self-perceived competency in each respective skill. P-value is calculated using the Wilcoxon Signed-Rank test.

Table 5. Average scores for each student in the group 1

Student	Average scores	Student	Average scores
1	9.23	10	9.16
2	9.31	11	9.46
3	9.19	12	9.37
4	9.35	13	9.41
5	9.39	14	9.51
6	9.34	15	9.39
7	9.42	16	9.34
8	9.49	17	9.32
9	8.93	Average	9.33

Table 6. Average scores for each student in the group 2

Student	Average scores
1	9.87
2	9.66
3	9.53
4	9.39
5	9.51
6	9.73
7	9.28
8	9.84
9	9.83
10	9.49
11	9.56
average	9.60

Table 7. Average scores for each student in the group 3

Student	Average scores
1	9.87
2	9.66
3	9.53
4	9.39
5	9.51
6	9.73
7	9.28
8	9.84
9	9.83
10	9.49
11	9.56
average	9.60

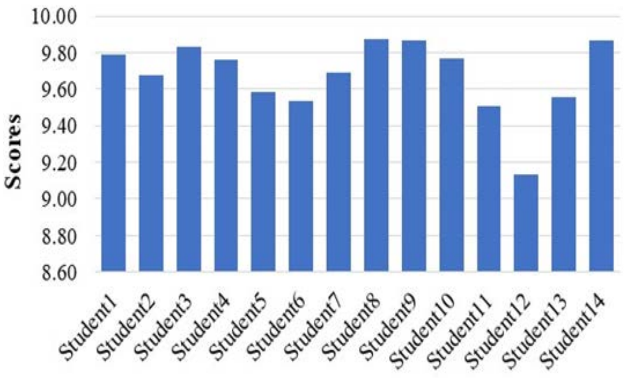

Figure 6. Average scores of peer reviewed results for each student in group 3

The project activities that were implemented have undergone evaluation. Students are required to submit three versions: the initial draft, the second draft and the final version. During the class discussions, feedback was provided to help students revise their projects. Figure 3 illustrates the average score changes on a 10-point scale with the data summarized in Table 3. Notable improvements were observed from the first draft to the second draft. Particularly, the mechanism of action at the molecular level posed challenges due to limited available information. Improvements were made in the data analysis section between the two drafts. Stady enhancements were seen in the introduction section and literature synthesis at the end. To further validate the impact of the project, statistical analysis was conducted, and the quantitative results are presented in Table 4. The table has six columns. The first column lists the different aspects or components being evaluated. The second and third columns ("pre" and "Range") represent the initial or baseline values and ranges for each aspect before the project started. The fourth and fifth columns ("post" and "Range") show the final results and ranges for each aspect after the completion of the project. The sixth column ("P") represents the p-value, which is a statistical measure of the significance of the observed changes or differences between the pre and post values. The last three columns ("Improved (n)," "No change (n)," and "Decrease (n)") indicate the number of participants that showed improvement, no change, or a decrease, respectively, for each aspect. For "introduction," the initial average value was 7.0 (range: 6-8), and the final average value was 9.5 (range: 8-10). The p-value is 0.00243, which is less than 0.1, indicating a statistically significant change. Additionally, 11 groups showed improvement, and 1 group showed no change. For "Mechanism of action". the initial average score was 4.8 (range: 0-8), and the final average was 9.6 (range: 9-10). The p-value of 0.00243 suggests a significant change, with 12 groups showing improvement. The "Quantitative Analysis" aspect had an initial average of 6.8 (range: 0-9) and a final average score of 9.8 (range: 8-10). The p-value of 0.00368 indicates a significant change, with 12 groups showing improvement. For "Literature synthesis," the initial average is 6.9 and a final average of 8.8. The p-value of 0.00218 indicates a significant change with all groups showing improvement.

The Table 4 presents a summary of the changes observed in various aspects before and after completion of the project. Significant improvements were achieved post - project. The data before and after completion of the project differs significantly. Difference is unlikely to occur by chance based on the results in Table 4. We reject the null hypothesis that there is no difference between the rank of two groups of data. Before and after project completion, the U-value is 1.5. The critical value of U at $p < 0.01$ is 27, indicating statistical significance. Therefore, the result is significant at $p<0.01$. The Wilcoxon Signed-Rank test for project design shows a significant difference between before (Mdn=0.7, n=12) and after (Mdn=0.95, n=12, Z=3, p=0.00243, r=0.9). Similar results are observed for the other learning outcomes: Mechanism of action (before Mdn=6 and after Mdn=10, Z=3, p=0.00243, r=0.9), quantitative analysis (before Mdn=8, after after Mdn=10, Z=2.9, p=0.00368, r=0.9), and Literature analysis (before Mdn=8 and after Mdn=9, Z=3.1, p=0.00218, r=0.9). The table suggests that the project or study resulted in significant improvements across different aspects, as indicated by the higher post-project averages and the low p-values. It is commendable that students demonstrated dedication and concentration during the assigned activity as evidenced by the drastic improvements across all sections of the project in such a short time. Overall, the project resulted in consistent improvements across the evaluated aspects.

Peer review evaluation

Peer perceived evaluation among students was incorporated into the project evaluation process. This educational practice offers several significant benefits:

1. Enhanced learning: By reviewing their peers' work, students gain exposure to different perspectives, approaches, and ideas, which can deepen their understanding of the subject matter. 2. Increased engagement: Active participation in the assessment process can increase student engagement with the learning material.

The peer review results were analyzed across three groups: Group 1, Group 2, and Group 3. Here are the key findings:

1. **Group 1**: Students in this group assigned relatively high scores, averaging 9.33 out of a 10-point scale (ranging from 8.93 to 9.51). The data is summarized in Table 5, and the corresponding plot is shown in Figure 4.
2. **Group 2**: Students in Group 2 exhibited even higher average scores, with an average of 9.60 out of 10 (data from Table 6, visualized in Figure 5).
3. **Group 3**: The highest average scores were observed in Group 3, reaching 9.67 out of 10 (ranging from 9.13 to 9.88). The relevant data is presented in Table 7 and visualized in Figure 6.

Key observations in the peer review process are as follows: Consistently high scores across all groups suggest that students view their peers' performance positively. The ranges are relatively narrow, indicating consistency in ratings. This could indicate a collaborative and supportive learning environment. Despite the potential limitations in score differentiation, the benefits of peer review cannot be neglected. Peer review offers several valuable benefits for students:

1. **Enhanced Learning**: Through exposure to different perspectives, peer review helps students engage more deeply with learning materials.
2. **Obstacle Handling**: Students observe how their peers tackle projects and address obstacles, which can inspire their own learning and improvement.
3. **Desire to Learn**: Witnessing effective approaches from peers can stimulate students' motivation to learn and excel in their projects.

In conclusion, while the peer review process offers valuable learning opportunities, the current evaluation results show limited differentiation and potentially inflated scores. This suggests a need for refining the peer review process to enhance its effectiveness as an assessment and learning tool in the future.

4. Discussion

Incorporating research competencies into the courses at the undergraduate is one of the important modern teaching practices. By nurturing research skills early in students' academic journey, within a contextual framework, we empower them critical thinking abilities with real-world applications. [15] Research and problem-solving skills are essential across various professional fields. To effectively integrate research experiences into clinical chemistry curricula, professors must grasp research methodologies and critically evaluate relevant experiences. [16]

A research-based pedagogical approach is a powerful teaching method that can significantly improve student learning and personal growth. This involves strategically applying current best practices to go beyond traditional academic boundaries and improve student learning outcomes. This teaching method, which has been widely applied, has shown promising results in clinical chemistry instruction, particularly benefiting the underrepresented groups. Clinical technologists play a vital role in diagnosing diseases through laboratory data collection for individuals and populations. The student body in the clinical chemistry course are often from diverse backgrounds including ethnic minorities and first-generation college attendees - who may lack prior exposure to education and research. By integrating a research component into clinical chemistry education, we address this barrier practically. Not only does it enrich student learning, but also stimulates students' curiosity and cultivates critical thinking, a valuable skill across all professions.

Incorporating research component into the course curriculum is **crucial** for several reasons: [17,18]

1. **Relevance:** Research based problems bridge theoretical concepts to practical applications, making the material more relevant and engaging for students.
2. **Critical Thinking:** Addressing research challenges encourages critical thinking, problem-solving, and creativity. Students learn to apply their knowledge authentically.
3. **Preparation:** Exposure to real-world issues equips students with practical skills and insights, preparing them for their future careers.
4. **Motivation:** When students witness the impact of their work through research-based experience, they become more motivated and invested in their learning.

While the integration of research-based practices into the clinical chemistry curriculum has yielded notable enhancements in student learning, particularly in critical thinking and research capabilities, it's important to acknowledge certain constraints. The elevated peer review scores suggest there might be room to improve the evaluation criteria or to offer more comprehensive training for students on delivering effective feedback. Advancing this practice could see gains from a peer review system that promotes a broader range of feedback, pushing students to be more thorough and diverse in their critiques.

5. Conclusion

In summary, adopting a research-oriented method in teaching clinical chemistry has positively influenced student learning outcomes, especially in understanding intricate molecular mechanisms using the data provided by the literature. Students demonstrated a high level of commitment and focus during the course activities associated with this pedagogical approach. Thus, incorporating a research component into this course curriculum revealed great potential for future educational initiatives. These results can contribute to developing teaching strategies that weave science into clinical chemistry curriculum, thereby providing students with scientific knowledge that extends beyond the classroom. It not only broadens the educational experience but also stimulates students' curiosity and develops critical thinking skills, essential in all professions.

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