



CHALMERS
UNIVERSITY OF TECHNOLOGY

Learning by teaching efficiently enhances learning outcomes in molecular biology of the cell course

Downloaded from: <https://research.chalmers.se>, 2024-04-18 14:35 UTC

Citation for the original published paper (version of record):

Mijakovic, I., Rahimi, S. (2024). Learning by teaching efficiently enhances learning outcomes in molecular biology of the cell course. *Biochemistry and Molecular Biology Education*, 52(1): 15-24.
<http://dx.doi.org/10.1002/bmb.21784>

N.B. When citing this work, cite the original published paper.

ARTICLE

Learning by teaching efficiently enhances learning outcomes in molecular biology of the cell course

 Ivan Mijakovic^{1,2} | Shadi Rahimi¹ 

¹Division of Systems and Synthetic Biology, Department of Life Sciences, Chalmers University of Technology, Gothenburg, Sweden

²The Novo Nordisk Foundation Center for Biosustainability, Technical University of Denmark, Lyngby, Denmark

Correspondence

Shadi Rahimi, Division of Systems and Synthetic Biology, Department of Life Sciences, Chalmers University of Technology, Kemivägen 10, SE-412 96, Göteborg, Sweden.
Email: shadir@chalmers.se

Funding information

Kristina Stenborgs Foundation for Scientific Research, Grant/Award Number: C 2021-1705; Novo Nordisk Fonden, Grant/Award Number: NNF20OC0064547; Stiftelsen Åforsk, Grant/Award Number: 23-299

Abstract

To evaluate the impact of active learning approaches in a basic molecular and cell biology course for undergraduate students, we assessed the effect of learning by teaching and peer review on the learning outcomes. A literature seminar activity with peer review and feedback was organized as a compulsory activity for all students, covering about 25% of the course content. The remaining 75% of the course was delivered as classical lectures. The students collaborated in groups to present the content of a review article complemented with a research article. For each group of students, an opponent group was assigned to challenge the presenting group by questions and contribute to the evaluation of the presentation together with the teacher. Based on the feedback survey, the students reacted positively to this active learning exercise, and they strongly recommended keeping it in the future editions of the course. The students' exam scores strongly indicated that the learning outcomes from the learning by teaching part of the course were consistently higher than from the classical lecture part of the course. Further optimization of the active learning part of the course is outlined based on student feedback.

KEYWORDS

active learning, learning by teaching, literature seminar, peer review

1 | INTRODUCTION

Given the increasing competitive demands both in academia and industry, the management educators need to provide the most productive classrooms with improved teaching methods making students ready for their future careers. For many years, professors and instructors merely transferred their knowledge to the students and students were expected to passively receive and memorize the information. That process was characterized as passive learning.¹ This traditional lecture-based learning

is generally known to induce compliance and passivity, since it is based on a one-way knowledge transfer.

Exploration of best approaches for teaching led to the emergence of the active learning concept in the early 90's,² and today active learning methods, based on the learner-centricity, are the preferred approach.³ Active learning has been verified to develop competitive skills in students, empowering them to address the society problems much more actively once they enter to the labor market. In this approach, the responsibility of learning is with the students themselves and the teacher acts as a

This is an open access article under the terms of the [Creative Commons Attribution](https://creativecommons.org/licenses/by/4.0/) License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2023 The Authors. *Biochemistry and Molecular Biology Education* published by Wiley Periodicals LLC on behalf of International Union of Biochemistry and Molecular Biology

guide. Therefore, the students can learn on their own using active learning activities.

There are several documented advantages of active learning approaches, including increased knowledge, development of creative and critical thinking, enhancing problem-solving, interpersonal, and collaborative skills for students, all of which makes this approach increasingly attractive.

One of the basic active learning approaches is “learning by teaching.” As Peter Drucker, a leader in the development of management education said, “No one learns as much about a subject as one who is forced to teach it.” In this method, the students teach their classmates, and the teacher acts as moderator to ensure the learning process goes properly. In this way, the students get actively involved in their learning process. Furthermore, in this peer learning approach, learning from peers is enhanced by the fact that other peers have already been in a similar learning situation, so they can help learners to solve the immediate problems.^{4,5} In other words, the term “peer learning” means that the different people with diverse levels of knowledge who are in similar situation can share their knowledge, experience, ideas, and concepts. It can be also defined as a way of acquiring knowledge with the support and help from a group of peers while both learners and tutors getting benefit out of this multidirectional exchange of information.⁶ In the old-fashioned model of this approach, senior students teach the junior students. In a more modern approach, students from the same year assist and cooperate with each other to go through the course material. Peer learning can occur formally and informally. The formal way is when group work is organized within the course. The informal way is when students discuss projects, assignments, exams, and lectures in a casual situation.

Nowadays, peer learning is increasingly becoming an essential part in many courses, in a variety of contexts and disciplines, and in many countries. This approach was also successfully applied to different areas of education like biology, medical, engineering, English as a foreign language (EFL), information technology (IT), and design educations.^{7–12}

Peer review is another active learning approach, where the students are required to critically think and comment on the materials provided by their classmates. The question we would like to address is how the teachers can make use of these two approaches of “learning by teaching” and “peer review” to design an improved teaching method and provide better-quality learning process for students. Therefore, in this educational research paper, we decided to assess the effect of these two active learning approaches on providing favorable outcomes for students in terms of grades, perception

about the usefulness of the course, and satisfaction with the course. The effect of learning by teaching approach was investigated using a literature seminar activity organized in the course cell and molecular biology 2 given in 3 continuous years, from 2020 to 2022 at Chalmers University of Technology. The aim of this pedagogical activity was to teach the students how to read, analyze, explain, and present the research published in scientific journals to an audience with same level of knowledge. It also trained the students in giving a public scientific presentation and participating in a public debate. Furthermore, using peer review approach, we aimed to teach the students about the important criteria for a proper presentation once they evaluate their classmates based on the criteria given in the evaluation sheet. The results of this study were quantified based on the final exam grades and students comments in a feedback survey.

2 | MATERIALS AND METHODS

2.1 | Course information

Cell and molecular biology 2 is a compulsory course with 4.5 credits given to 58 students of second year at bachelor's level (first cycle) in Chalmers University of Technology. The aim of this course is to complete the training of students of the Bioengineering program in molecular and cellular biology, by focusing specifically on phenomena related to multicellularity. Course-specific prerequisite was “Introduction to cell and molecular biology.” The course contained classical lectures, which cover the topics from the textbook *Molecular Biology of the Cell*, Alberts et al., 6th Edition. To test the effect of “learning by teaching” approach on the learning process, a literature seminar activity with peer review and feedback was organized as a compulsory activity for all students, covering about 25% of the course content. The remaining 75% of the course was delivered as classical lectures. Thus, the first sessions of the course were the classical lectures given by the teachers and the last five sessions were the literature seminars, followed by a literature seminar feedback and revision session. In the literature seminar feedback and revision session, we have tried to summarize and cover the literature sources given for the activity.

2.2 | Implementation method

For the literature seminar activity, each group of four to seven students was given scientific literature in the form of review and scientific peer-reviewed publications on

four different topics including “Mechanisms of coronavirus infection”, “Transmission and prevention of coronavirus”, “Therapy of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2)”, and “Vaccine against coronavirus.” The group was expected to present the studied material to the class by giving a 15-min public presentation for their colleagues. We have also supplemented peer review activity to this. For peer review activity, an opponent group was assigned for each presenting group and each presentation was followed by questions from the opponent group and the audience. The opponent group was expected to question and evaluate the quality of another group’s presentations based on the criteria in evaluation sheet provided by the teacher (Figure 1). Evaluation points included (i) timing, (ii) comprehensiveness, (iii) clarity, (iv) rehearsal, (v) development of discussion both about the scientific contents and ethics, (vi) balance, (vii) making a connection with the knowledge from classical lectures, and (viii) dependency on notes.

Based on the opponent group feedback, the teacher assigned the grades for the seminar activity. Participation in group work and literature seminar activity was compulsory.

2.3 | Evaluation method

To gain insight into students’ perception and satisfaction with the literature seminar activity, we have examined the feedback survey provided by the university for course round in 2022 (Figure 2). Positive and negative comments on literature seminar activity were counted from the survey. The students’ comments to the survey question on “what should be kept for the next round of course?” were also counted and expressed as the percentage.

The topics of the literature seminar exercise were a part of the final written exam. Provided review papers and the .ppt presentations constituted official course literature. The literature exercise was graded. The maximum total number of points a student can score is 100%. Students can receive a total of 14 points (14%) from attending the literature seminar. In addition, the topics covered in the literature seminar are a part of the course curriculum, covered in the written exam (10 points/10%). Therefore, students can earn in total 24 points (24%) of the final grade from the literature seminar exercise.

The student learning outcome was measured by total points (expressed as the percentage) that student got from

<p><u>Evaluation sheet.</u></p> <p>I am opponent for group: _____ Topic: _____ Date: _____</p> <p>REMINDER: A committee composed of the teachers and opponent group will evaluate the quality of your presentation and answers according to criteria listed below. Use positive evaluation, with this I mean that you should focus most attention on what is good rather than to look for errors/mistakes. Teachers will assign grades.</p> <p>Send your evaluation sheet to teacher after the evaluation meeting. You do not need to write your own name on it.</p> <p>Criteria definition for the evaluation:</p> <ol style="list-style-type: none"> The group is keeping to time (finish presentation within 15 minutes). (Yes / No) The group has delivered a presentation that contains all compulsory elements. (Yes / No) How clear / easy of the presentation is understood by the listener? (1 or 2 or 3) <ol style="list-style-type: none"> Several parts are unclear to the listener, and the group seems to have insufficient knowledge of their topic. Many parts are clear / easy to understand for the listener, and the group has good knowledge of their topic. Most parts / entire presentation are clear / easy to understand for the listener, and the group has excellent knowledge of their topic. How well of the presentation is rehearsed? (1 or 2 or 3) <ol style="list-style-type: none"> The presentation is not well-rehearsed, and transitions are not well arranged between speakers and between different elements of the presentation. The presentation is good and moderately supported by the ppt slides. The presentation is well-rehearsed and excellently supported by the ppt slides. The transition between speakers and between different elements of the presentation is smooth and logical. Can the group develop a discussion regarding both scientific contents and ethical issues? (1 or 2 or 3) <ol style="list-style-type: none"> The group’s ability to discuss the topic is limited. The group’s ability to discuss the topic is moderate. The group has excellent knowledge of their topic and can develop a deep discussion. The presentation is very well balanced in terms of topic overview / results (data) / ethics / summary. (Yes / No) The group connects its topic to learned knowledge and clearly indicates in the presentation. (Yes / No) <p>The committee can consider deducting 1 point from the agreed upon score if:</p> <ol style="list-style-type: none"> The group is not keeping to time (note that if you exceed 15 minutes you may also be interrupted). (Yes / No) The group uses written notes extensively (e.g. most of group members reads out of their written scripts). (Yes / No) <p style="text-align: center;">1</p>	<p><u>Evaluation sheet.</u></p> <p>Notes:</p> <p>_____</p> <p>Positive points:</p> <p>_____</p> <p>Points for improvement:</p> <p>_____</p> <p style="text-align: center;">2</p>
---	---

FIGURE 1 Evaluation sheet provided by teacher for peer review activity.

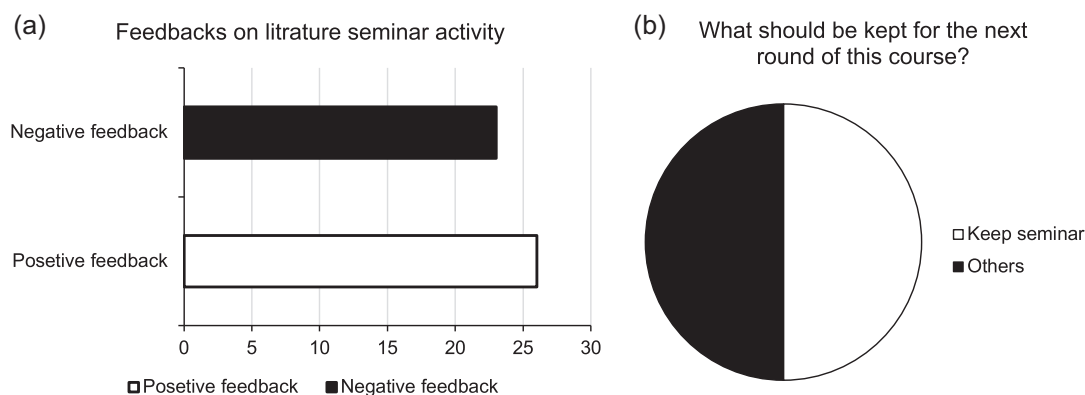


FIGURE 2 The students were positive to the literature seminar activity according to students' feedback survey. (a) Positive and negative comments on literature seminar activity were counted from the survey. (b) The students' comments to the survey question on "what should be kept for the next round of course?" were counted.

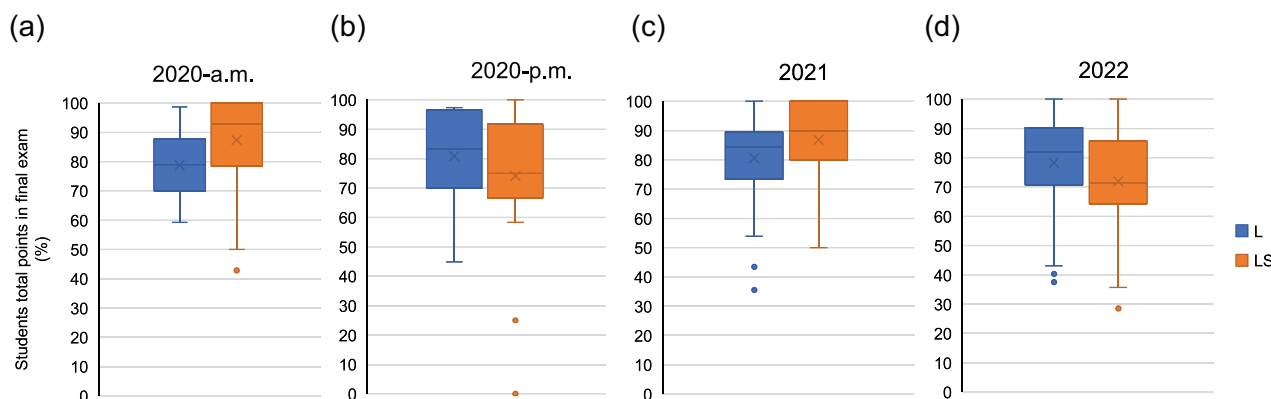


FIGURE 3 Teaching positively affects students learning outcome in 2020-a.m. and 2021 exams. The total points (expressed as the percentage) that students got from literature seminar (LS) (orange) and classical lecture (L) (blue) parts in different final exams. 2020-a.m., 2020 morning exam; 2020-p.m., 2020 afternoon exam.

literature seminar (LS) and classical lecture (L) materials questions in the final exam (Figure 3). For comparison, we included the related total points from the final exam of students in three continuous rounds of the course (2020–2022) that basically used the same type of literature seminar activity but with different literature as the material. As two rounds of exam were held, one in the morning and one in the afternoon for the students in 2020, and the questions were obviously different, we have evaluated those two exam sessions independently.

Furthermore, the median of students' total points (expressed as the percentage) from questions on literature seminar (LS) activity was compared with the median of students' total points from questions on classical lecture (L) material (Figure 4).

The final grade for the course is given as follows: 0%–45%, U; 46%–65%, 3; 66%–85%, 4; 86%–100%: 5. Thus, the median of students' points (expressed as the

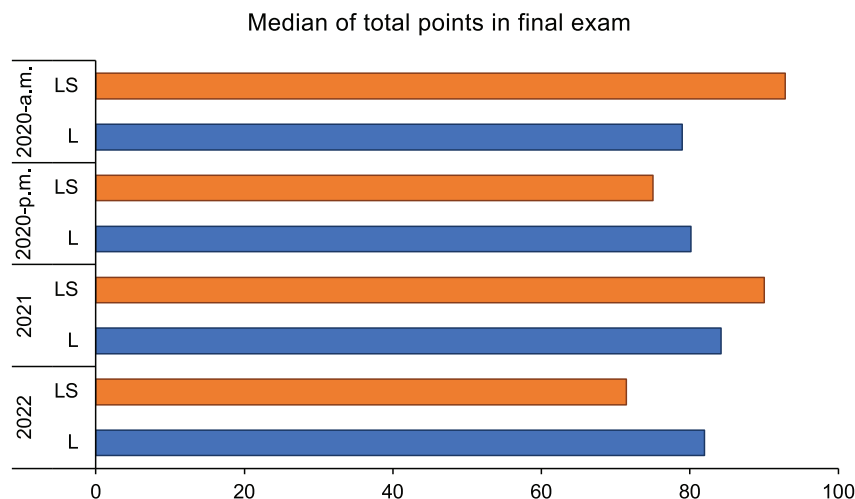
percentage) from individual questions on literature seminar and classical lecture was arranged as the heatmap for the students classified based on their final total points/grade.

3 | RESULTS AND DISCUSSION

3.1 | Students feedback on literature seminar activity

The courses are expected to develop students with transferable skills, generic attributes or capabilities, key competencies such as teamwork and interpersonal skills that employers esteem highly. In this course literature seminar activity, the students were involved in an interactive learning process and there were several transferable skills that students could develop as following:

FIGURE 4 Teaching positively affects students learning outcome in 2020-a.m. and 2021 exams. Median of totals points (expressed as the percentage) that students got from questions on literature seminar (LS) (orange) and classical lecture (L) (blue) parts. 2020-a.m., 2020 morning exam; 2020-p.m., 2020 afternoon exam.



1. They collaborated in a group, and they could learn how to work in a group by teamwork. This activity was based on cooperative learning, where students worked together to maximize their own and each other's learning.¹³
2. They presented the literature, and they were expected to respond to questions from the opponent group and audience; thus, they could develop presentation and communication skills.
3. They developed creativity while making slides to transfer the message properly. For example, a group used online tools like BioRender to make more attractive slides.
4. The students were evaluated by other students in the opponent group based on the evaluation sheet provided by teacher. From this, the students were able to learn about the key points to prepare a good presentation.
5. Since the opponent groups contributed to evaluation of the presenting groups, they would develop critical thinking skill. Students in the opponent groups developed their skills in interpreting and questioning scientific content, evidence-based debate skills, and collaborative skills during the discussion sessions.

Therefore, the main advantage of this peer learning activity could be summarized as promoting transferable skills that students can apply to the real-world professional settings.

One typical classroom observation is that the students were very engaged in the activity and some groups used more literature resources than what they were given as a basis. Most of the students (around 80%) were happy with the literature seminar activity when the teacher orally asked for feedback.

From the written feedback survey, we have received more than 50% positive comments (26 positive

vs. 23 negative comments) on the activity (Figure 2a). From the negative comments, we could observed several types of students' resistance to the activity. For example, a student stated in the feedback survey that they would prefer to have four lectures by teacher instead of students taking all that time. This was an example of open resistance, in which a student openly voiced concerns or objections.¹⁴ There were also some students who were poorly prepared showing their minimal efforts for the activity that are classified as the partial compliance.¹⁴ In fact, active learning needs extra contribution and effort from students that may be in conflict with their expectations, resulting in some extent of resistance to the participation in the active learning exercises. As an example, a student stated that "the project took half of the whole course, versus only four questions on the exam... so it didn't match up." Only 5 out of 16 sessions of the course were based on the seminar activity, but as this student explained, the active learning part took much more effort.

In addition, there was some interesting feedback about learning objectives. For example, one student stated, "I felt like the point was rather to make a good presentation than actually learning the topic." Learning the topic and learning how to make a good presentation were our learning objectives for this activity; however, the student felt that good presentation was the main focus. This is an example of mismatched expectations that can be addressed in the beginning of the activity, by clarifying to the students that both aims are equally important.

Among the students' comments, some stated that they would expect the teacher to be more involved in grading the presentations than their opponent classmates. One student stated, "the last mini-conference lecture with general feedback wasn't very helpful, it would be much better if each group met individually with the teachers to

discuss their grade and feedback.” These will be important considerations for the future editions of the course.

In the feedback survey, in reply to the question “What should be kept for the next round of this course?” 50% of students’ comments suggested to keep the literature seminar for the next round of this course and the other 50% of comments requested to keep something unrelated to the seminar activity (Figure 2b).

Despite many advantages of active learning, there is a disadvantage of taking up more of students’ time. However, our students considered the course as being balanced in terms of time and effort. They mentioned that they spent long time for this seminar activity, but in turn they could get points out of it for their final grades. When it comes to other types of courses, a self-learning approach usually leads to very positive student feedback. For example, learning about a professional subject in IT, based on analyzing and research on a selected theme, writing and presenting a seminar work, followed by a debate in class, was highly appreciated by the students.¹¹ In engineering education, a large number of students expressed preference for seminar presentations compared with classical lectures, both after the completion of the course and after the final examination.⁸

Overall, the feedbacks on active learning exercise were mainly positive and it was strongly recommended to be kept in the future rounds of course. Furthermore, a considerable number of students showed some form of resistance.

3.2 | Literature seminar activity improves learning

It was already found that learning can be enhanced through teaching others, and that students who teach the material show better understanding and retention of knowledge. To demonstrate the effect of teaching on learning process, we first compared total points (expressed as the percentage) that students got from the literature seminar (LS) and classical lecture (L) parts in the final exams (Figure 3). As it clearly shown in Figure 3, most of the students got 80%–100% of total points from LS part in 2020-a.m. (morning exam) and 2021 exams. The score on questions based on classical lectures was lower: 70%–90% of total points.

We also compared the median of total points (expressed as the percentage) that students got from questions coming from literature seminar (LS) and classical lecture (L) part. As indicated (Figure 4), the median of total points from LS questions was 6%–14% higher than total points from L questions in 2020-a.m. and 2021

exams. However, median of total points from L questions was only 5%–10% higher than median of total points from LS questions in 2020-p.m. (afternoon exam) and 2022 exams. Thus, the outcome of learning by teaching is somewhat variable from year to year in the same course.

Next, we classified the students based on their final grades into three different groups, scoring 46%–65%: Grade 3, 66%–85%: Grade 4, and 86%–100%: Grade 5. Then median of students’ points from individual questions on literature seminar and classical lecture parts were indicated as the heatmap in Figure 5. As it was demonstrated, the students with the final grade of 66%–85%: 4 replied better to the questions coming from the literature seminar compared to the questions coming from the classical lecture material in 2020-a.m. and 2021 exams. However, this effect was not observed for group of 2020-p.m. who attended the same course but had a different exam. This can be explained by difficulty of LS questions for 2020-p.m. group. This might also explain the bad performance on LS questions for 2022 seen in Figure 5. In addition, one observation was that everyone (including the well-performing students) had bad performance on LS questions 14 and 15 that was related to the therapeutic approaches and candidate vaccines against SARS-CoV-2 virus. This might be due to the difficulty of these specific subjects compared to those given to students from different rounds of the course (e.g., malaria, influenza).

We also examined the number of students who got the final grades of 5, 4, 3, and U (fail) at different rounds of the course (Figure 6). The number of students with the top grades (5 and 4) was higher (88% and 96%) in the 2020-a.m. and 2021 exams, that is consistent with the effect of teaching by learning on learning outcomes in related exams. This interesting observation refers to the point that the students in 2020-a.m. and 2021 years might be better students overall (also substantiated with their success in other courses) and the makeup of students in any given class is an important factor affecting the outcome of the seminar activity.

Altogether, from the points that students got from literature seminar questions in final exams as a measure of learning outcomes of active learning, we can conclude that overall success of learning by teaching was higher than that of the classical lecture setup in some rounds of the course. Interestingly, the students with grade 66%–85%: 4 were more successful in providing correct answers to the literature seminar questions compared with lecture questions. In accord with our results, it was reported that the engagement activities such as seminars in introductory first-year biology classes for biology and nonbiology majors are associated with many positive outcomes, including

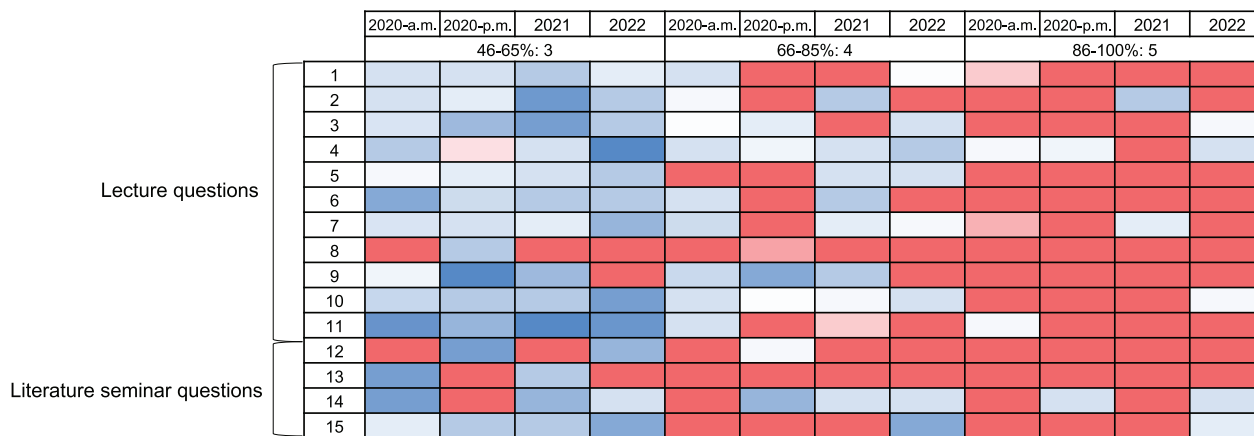


FIGURE 5 The students with final grades of 66–85%: 4 replied better to the questions coming from literature seminar. The students classified to three groups based on their final grades 46%–65%: 3, 66%–85%: 4, and 86%–100%: 5. The median of points (expressed as the percentage) that students got from individual questions on literature seminar and classical lecture material was shown as the heatmap for different rounds of course at different years.

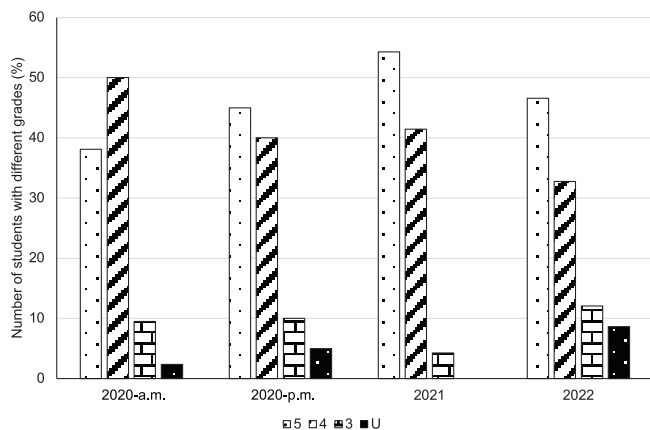


FIGURE 6 The number of students with final grades of 5, 4, 3, and U at different rounds of course, expressed as percentage.

improved student performance and positive perceptions of the experience. However, students in nonbiology majors like physical science majors (chemistry, physics), engineering, and nonscience majors demonstrated notably weaker relationships between their engagement and performance in biology courses.⁷ Similar to our results, there are several studies suggesting that at the higher education level, the more students engage and participate in their learning process, the more they could understand and recall the knowledge.^{15–17}

The seminar teaching method can be helpful to attain the purpose of fully mastering knowledge points and improving learning scores.^{18,19} There are also some examples of successful application of learning by teaching technique in other areas of education. Zeng et al.,¹⁰

investigated the effects of seminar teaching method versus lecture-based learning in medical education. This meta-analysis demonstrated that the seminar teaching method is an effective method for improving active learning ability, knowledge scores, skill scores, classroom atmosphere, student collaboration, and interaction between students and teachers. Al-Amri⁹ designed student-led seminars to help procrastinators study EFL. This produced significantly higher exam scores. Even in engineering education, Senthil⁸ proved that the seminar presentations led to higher number of top-grade students compared with the lectures. Coorey¹² proposed peer learning as an engaging method to augment teaching technology in design education. Students including technology teams, technology checklists, and group software challenges participated in this exercise throughout the course. The method produced lifelong learners, increased their leadership skills, and promoted a collaborative learning community. Thus, it can be concluded that learning by teaching method is also efficient method in other areas of education other than biology courses.

It should be noted that learning by teaching could conditionally be effective to enhance teacher's learning.^{20–22} For example, Hoogerheide et al.²⁰ showed that learning could be improved by explaining to others on video; however, explaining in writing could not yield the same benefits as on video. It was also reported that both initial explanation and interaction phases contribute to learning by teaching face-to-face, while the phase of preparation for teaching does not.²³ The interaction between the teacher and student, including delivering explanations, additional complementary explanations, questioning and responding,

and giving and getting feedback, is proposed as the key point for an effective learning by teaching.²⁴ Hence, within our pedagogical activity, we use the “peer review” approach to create a more interactive environment between students who are teachers and those who are their opponents (and audience).

One positive effect of “learning by teaching” approach on learning is due to retrieval practice.²¹ Being compelled to retrieve what they have studied while they are teaching could improve students’ learning. For our literature seminar activity, it was highly recommended to students to not rely on their notes. We also noted in our evaluation sheet that the opponent group could deduce one point if most of presenting group members extensively use their written script. Despite this, we could still notice some of the students using their notes frequently that might reduce the learning benefit of teaching.

Besides the evident effect of teaching on learning process within our pedagogical activity, we would reflect the effectiveness of cooperative learning. It was already proved that students can have better results when working together and understanding team dynamics.²⁵ Hence, active learning by teaching as well as working in a group could both potentially improve learning outcomes.

3.3 | Areas for improvement

Our analysis helped us identify several areas for improvement of this course, as follows.

3.3.1 | Assignment guideline

Literature seminar assignment guidelines should be made more clear and should be followed strictly. In this situation, the course instructions need to shift from only explaining how to teach and delivering the teaching material, towards explaining also what the teacher expects from students to be able to do with the course material. In other words, the instructions need to better clarify the expectations and learning outcomes.

3.3.2 | Group size

Determining the optimal group size in peer discussions for improvement of students learning and performance introduces an intensive debate in psychology while mixed findings were provided in the field and laboratory settings. Some of the groups in our activity have more members than other groups because more members signed up in that group (choosing a group is voluntary).

However, more strictly defined group size of for example, four to five people would be recommended since the workload for all group members would be even. Along these lines, Corrége and Michinov²⁶ also suggested that the group size of four individuals might be the optimal configuration to improve peer learning in group discussions.

3.3.3 | Group cooperation

There will be different ambitions for different people in the group activities. Thus, it is normal that some people would like to spend more time on this exercise, but some would not. As stated in the previous section, the smaller size groups may help to solve this problem by making homogenous groups where all participants agree on expectations in terms of workload.

3.3.4 | Topic

The subjects for literature seminar activity should be updated and diversified in the future rounds of the course.

3.3.5 | Grading

It is important that teacher gets actively involved in grading and does not only follow the grading and comments by opponent groups. The students assumed that opponent group is not adequately qualified for grading students. One issue with the evaluation would be that some people in the group were well-prepared while some were only reading from notes, thus it would be hard to evaluate the group (everyone in a given group is supposed to get the same grade). We assume that small group size may help to solve this problem as well, leading to similar level of efforts from all group members. It was already found that the increase in group size reduces the motivation, cooperation, and effort from individuals to collaboratively work on a task. In fact, it may lead to “social loafing” effect in large groups, which means that the level of effort would be lower when a person is judged in a large group compared to when the same person is working alone or judged individually.^{27–32} Interestingly, Shimazoe and Aldrich³³ demonstrated that the maximum group size should be four because above this the tendency to “loaf” increases with group size. Accordingly, we conclude that the group size of four can be optimal group size for this activity leading to equal effort from whole group members.

3.3.6 | Regular literature seminar activities throughout the education program

We observed that some students were completely new to public presentations, and they could not manage to make enough correlation between what they were teaching and what they were showing in their slides. Therefore, it is highly recommended to organize such active learning exercises in more courses to help students to gradually develop their presentation skills.

ACKNOWLEDGMENTS

This study was supported by a grant from the Novo Nordisk Foundation [NNF20OC0064547], a grant from Kristina Stenborgs Foundation for scientific research [C 2021-1705], and a grant from Stiftelsen ÅForsk [23-299].

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

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

ORCID

Shadi Rahimi  <https://orcid.org/0000-0002-8376-9880>

REFERENCES

- Wingfield SS, Black GS. Active versus passive course designs: the impact on student outcomes. *J Educ Business*. 2005;81:119–23.
- Bonwell CC, Eison JA. Active learning: creating excitement in the classroom. ASHE-ERIC higher education report no. 1. 1991 Washington, DC: The George Washington University, School of Education and Higher Education.
- McGreevy KM, Church FC. Active learning: subtypes, intra-exam comparison, and student survey in an undergraduate biology course. *Educ Sci (Basel)*. 2020;10:185.
- Boud D. Introduction: Making the move to peer learning. In: Boud D, Cohen R, Sampson J, editors. *Peer learning for higher education*. London: Kogan Page Limited. 2001, p. 1–20.
- Keppell M, Au E, Ma A, Chan C. Peer learning and learning-oriented assessment in technology-enhanced environments. *Assess Eval High Educ*. 2006;31:453–64.
- Topping K. Peer tutoring: old method, new developments / Tutoría entre iguales: método antiguo, nuevos avances. *Infancia y Aprendizaje*. 2015;38:1–29.
- Hymers D, Newton G. Investigating student engagement in first-year biology education: a comparison of major and non-major perception of engagement across different active learning activities. *Can J Scholarship Teach Learn*. 2019;10:1–22.
- Senthil R. Enhancement of engineering education by incorporating active learning methodologies. *J Eng Educ Transform*. 2020;34:2349–473.
- Al-Amri M. Student-led seminars as an active learning strategy to enhance English as a foreign language procrastinating students' achievement. *Learn Teach Higher Educ Gulf Perspect*. 2018;15:2–13.
- Zeng HL, Chen DX, Li Q, Wang XY. Effects of seminar teaching method versus lecture-based learning in medical education: a meta-analysis of randomized controlled trials. *Med Teach*. 2020;42:1343–9.
- Pelleh M. A free active learning approach to an information technology seminar course. *Proceedings of the 2014 InSITE Conference*. 2014 225–231.
- Coorey J. Active learning methods and technology: strategies for design education. *Int J Art Des Educ*. 2016;35:337–47.
- Johnson DW, Johnson RT. Cooperative learning: The foundation for active learning. *Active learning—Beyond the future*. 2018:59–71.
- Shekhar P, Prince M, Finelli C, Demonbrun M, Waters C. Waters integrating quantitative and qualitative research methods to examine student resistance to active learning. *Eur J Eng Educ*. 2019;44:6–18.
- Lo CC. Student learning and student satisfaction in an interactive classroom. *J Gen Educ*. 2010;59:238–63.
- McKeachie W, Svinicki M. *McKeachie's teaching tips: strategies, research, and theory for college and university teachers*. Boston: Houghton Mifflin; 2012.
- McMullen VB. Using student-led seminars and conceptual workshops to increase student participation. *Coll Teach*. 2014; 62:62–7.
- Kurczek J, Johnson J. The student as teacher: reflections on collaborative learning in a senior seminar. *J Undergrad Neurosci Educ*. 2014;12:93–9.
- Spruijt A, Leppink J, Wolfhagen I, Bok H, Mainhard T, Scherpbier A, et al. Factors influencing seminar learning and academic achievement. *J Vet Med Educ*. 2015;42:259–70.
- Hoogerheide V, Deijkers L, Loyens SMM, Heijltjes A, van Gog T. Gaining from explaining: learning improves from explaining to fictitious others on video, not from writing to them. *Contemp Educ Psychol*. 2016;44–45:95–106.
- Koh AWL, Lee SC, Lim SWH. The learning benefits of teaching: a retrieval practice hypothesis. *Appl Cogn Psychol*. 2018;32:401–10.
- Jacob L, Lachner A, Scheiter K. Learning by explaining orally or in written form? Text complexity matters. *Learn Instr*. 2020; 68:101344.
- Kobayashi K. Learning by teaching face-to-face: the contributions of preparing-to-teach, initial-explanation, and interaction phases. *Eur J Psychol Educ*. 2022;37:551–66.
- Kobayashi K. Interactivity: a potential determinant of learning by preparing to teach and teaching. *Front Psychol*. 2019;9:2755.
- Hernández-de-Menéndez M, Vallejo Guevara A, Tudón Martínez JC, Hernández Alcántara D, Morales-Menendez R. Active learning in engineering education. A review of fundamentals, best practices and experiences. *Int J Interact Des Manufact*. 2019;13:909–22.
- Corrégé J-B, Michinov N. Group size and peer learning: peer discussions in different group size influence learning in a biology exercise performed on a tablet with stylus. *Front Educ (Lausanne)*. 2021;6:6.
- Ingham AG, Lvinger G, Graves J, Peckham V. The Ringelmann effect: studies of group size and group performance. *J Exp Soc Psychol*. 1974;10:371–84.

28. Petty RE, Harkins SG, Williams KD, Latane B. The effects of group size on cognitive effort and evaluation. *Pers Soc Psychol Bull.* 1977;3:579–82.
29. Latané B, Williams K, Harkins S. Many hands make light the work: the causes and consequences of social loafing. *J Pers Soc Psychol.* 1979;37:822–32.
30. Karau SJ, Williams KD. Social loafing: a meta-analytic review and theoretical integration. *J Pers Soc Psychol.* 1993;65:681–706.
31. Hamburger H, Guyer M, Fox J. Group size and cooperation. *J Confl Resolut.* 1975;19:503–31.
32. Komorita SS, Lapworth CW. Cooperative choice among individuals versus groups in an N-person dilemma situation. *J Pers Soc Psychol.* 1982;42:487–96.
33. Shimazoe J, Aldrich H. Group work can be gratifying: understanding and overcoming resistance to cooperative learning. *Coll Teach.* 2010;58:52–7.

How to cite this article: Mijakovic I, Rahimi S. Learning by teaching efficiently enhances learning outcomes in molecular biology of the cell course. *Biochem Mol Biol Educ.* 2023. <https://doi.org/10.1002/bmb.21784>