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Technology and innovation in teaching genetics: project-based learning in the construction of cloning strategies

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Abstract

Project-based learning (PBL) is an active student-centred form of instruction that uses a project as a central vehicle of knowledge acquisition. Besides its high potential in developing structured thinking, constructive investigations, and improving the students' responsibility and autonomy, this methodology is not strongly applied in Science degrees, where standardised tests and fixed protocol-driven laboratorial applications are still the dominant ways to assess academic achievement. This research involved the implementation of a PBL in teaching gene cloning strategies to third-year students of the BSc Biotechnology course. The methodology was conducted in four stages, integrating two curricular units, Genetic Engineering, and Integrated-Laboratories VB. Firstly, the project was conceptualised in Genetic Engineering theoretical classes with tutorial support. Secondly, the planned protocol was applied in the laboratory with tutor supervision. Thirdly, collaboration, communication, and reflection skills were emphasized with a poster presentation. Finally, an evaluation questionnaire was applied. The study's main findings were: 1) none of the students have ever had PBL, 2) the majority of students achieved better comprehension and acquired stronger theoretical knowledge, 3) they gained more autonomy in the laboratory, and 4) strongly recommended this methodology. However, students also acknowledged that the PBL approach was more time and study demanding.

Keywords: Cloning, Genetic engineering, Laboratories, PBL.

Resumo

A aprendizagem baseada em projetos (ABP) é uma forma ativa de ensino centrada no estudante que usa um projeto como veículo central de aquisição de conhecimento. Apesar do elevado potencial para desenvolver um pensamento estruturado, investigações construtivas e promover responsabilidade e autonomia, esta metodologia não é usualmente aplicada nas licenciaturas em Ciências, onde testes padronizados e práticas laboratoriais com protocolos fixos ainda são as formas dominantes de avaliação. Este estudo envolveu a implementação da ABP no ensino de estratégias de clonagem, com estudantes do terceiro ano da Licenciatura em Biotecnologia. A metodologia foi desenvolvida em quatro etapas, integrando duas unidades curriculares, Engenharia Genética e Laboratórios VB. Inicialmente, o projeto foi conceptualizado nas aulas teóricas de Engenharia Genética com suporte tutorial. Posteriormente, o protocolo planeado foi implementado no laboratório com supervisão. Em terceiro, as competências de colaboração, comunicação e reflexão foram enfatizadas com a apresentação de um poster. Por fim, foi aplicado um questionário de avaliação. As principais conclusões foram: 1) nenhum dos estudantes tinha experienciado a ABP, 2) a maioria compreendeu e adquiriu conhecimentos teóricos mais sólidos, 3) adquiriram mais autonomia no laboratório e 4) recomendam fortemente. No entanto, os estudantes reconheceram que a ABP consistiu numa aprendizagem mais exigente.

Keywords: Clonagem, Engenharia genética, Laboratórios, ABP.

1.Context

The introduction of Project-Based Learning (PBL) in higher education has proven to be an effective methodology to motivate and make students responsible for their learning process (Guo et al., 2020; Rusek, 2021). In partnership with other active methodologies, PBL has the potential to provide more meaningful and contextualized learning (Rusek, 2021). When challenged to build a project that aims to solve a specific problem, students are encouraged to take an active role and apply previously acquired theoretical knowledge in practice. Since these projects are normally developed in groups, skills such as critical thinking, communication, collaboration and autonomy, which are essential for academic and professional success, are also developed (Prochazkova et al., 2019).

Genetic engineering is a complex field that requires a strong grasp of advanced scientific principles and specialized technical skills to successfully execute cloning strategies in the laboratory. These strategies may include DNA manipulation, bacterial transformation, and cell culture, among other techniques. Cloning also involves multiple intricate steps that demand meticulous attention to maintain the stability and integrity of the cloned DNA. Learning to bridge the gap between the theoretical concept of a cloning strategy and its practical application is a challenging skill to acquire (Alozie et al., 2010). To overcome this hurdle and enhance learning, a teaching approach centred around a cloning project was adopted. Students were empowered to actively construct their experimental protocols, design strategies for their execution, and ultimately evaluate the results achieved. This approach transformed students from passive information recipients into proactive builders of their scientific knowledge.

2. Description of the pedagogical practice

The application of this project involved a theoretical approach thaught in the curricular unit of Genetic Engineering and trained the experimental approach in the curricular unit of VB Laboratories.

2.1. Objectives and target group

The main objective focused on the development and implementation of an experimental protocol describing the cloning strategies that would allow the production and easy purification of a recombinant protein. This project-based learning methodology was applied to students in the 3rd year of the degree in Biotechnology at the Escola Superior de Tecnologia do Barreiro of the Instituto Politécnico de Setúbal.

2.2. Methodology

The students were grouped into three practical teams, and each team was tasked with utilizing a distinct cloning strategy to achieve a common goal. The cloning strategy was developed into four stages: conceptualization implementation and execution; project showcase and learning outcomes evaluation phase. The main characteristics of the four stages are summarized in table 1.

Table 1
Summary of stage name, description with the main activities carried out, and competences acquired

Stage Name	Description	Competences
Conceptualization phase	Research and computer work using specific databases in Biomolecular Sciences and enzyme brand and cloning kit websites.	Application of theoretical knowledge to specific cloning problems, Ability to propose experimental strategies to address biological questions.
Implementation and Execution phase	Carrying out the different laboratory steps associated with cloning, such as restriction enzyme digestion, amplification, ligation, transformation and selection.	Handling specific equipment, Patience, Attention to detail, Precise documentation of scientific observations, Critical analysis of those observations, Organizational skills.
Project Showcase phase	Poster elaboration and presentation	Creativity, Attention to detail, Collaboration skills, Accountability, Communication skills, Time management.
Learning Outcomes Evaluation phase	Answer to a questionnaire	Critical thinking skills, Self-awareness.

As a result of the gene's characteristics and the multitude of available cloning strategies, specific genetic problems were posed. These problems depended on various factors, such as the properties of the cloning vector, the position of the His-Tag (at the N-terminus or C-terminus), and the presence of a potential signal peptide for secretion in the gene. Teamwork was consistently reinforced, and each group planned to test different PCR conditions. This allowed the class as a whole to complete optimization, including annealing temperature, buffer composition, and primer concentration.

To implement the developed cloning protocol, the students were allotted three 3-hour laboratory sessions. The intermediate results were reviewed and discussed in the Genetic Engineering theoretical classes. In the laboratory, the professor's primary focus was to ensure the proper handling of equipment and laboratory practices while providing the necessary reagents, equipment, and tools that the students requested. The students worked semi-autonomously and faced real-life laboratory procedures that were not previously tested.

As a result, not all procedures yielded positive results, demonstrating the need for optimization. Additionally, PBL strategy fostered the development of analytical and problem-solving abilities, effective communication of ideas, and the capacity to tackle unfamiliar challenges.

2.3. Assessment

Following the completion of the project, the students were asked to participate in an anonymous questionnaire consisting of two parts. Part A was designed to provide insight into the students' profiles, while Part B focused on evaluating the Problem-Based Learning (PBL) approach. The latter consisted of 12 randomly distributed questions (A to L) covering three topics and rated on a Likert scale of 1 to 5, with 1 indicating complete disagreement and 5 indicating complete agreement. The three topics included:
·Global satisfaction (n=4);
·Acquisition of knowledge (n=4);
·Comparison of PBL vs. traditional teaching methodology (n=4).

A total of 39 students provided their informed consent to utilize the data collected in the survey for statistical processing and academic purposes.

3. Discussion of results

All groups were able to develop and implement the cloning protocol, but not all achieved positive results. This added value to the learning process, as encountering non-results also contributed to defining the paths to follow and opting for new strategies in a real-life situation.

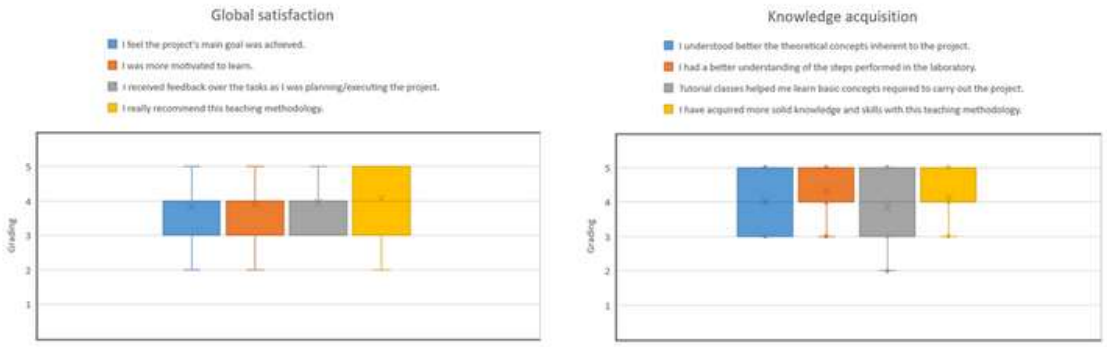
The students' profiles (N = 39), had an average age of 22.8 years (mode = 22 years), ranging from 20 to 44 years. The students were geographically dispersed across 16 municipalities, with 69% living in Setúbal, 26% in Lisbon, and 5% in two other municipalities. Despite being young people spread over multiple municipalities, 100% of the students had never engaged in project-based learning before.

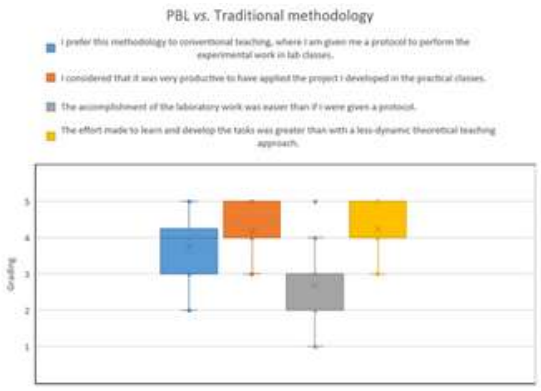
The data acquired in part B of the questionnaire focused on evaluating the Problem-Based Learning approach, as well as the four questions that were asked on each topic: Global satisfaction (I); Knowledge acquisition (II) and PBL vs. Traditional methodology (III), are represented in Figure 1. For each graph in Figure 1, the average value is represented by crosses, and the vertical bars indicate the minimum and maximum grades obtained for each question.

The implementation of PBL led to a notable level of satisfaction among students regarding the global aspects (Figure 1 (I)). A significant majority of students expressed that the objectives were accomplished effectively, they received adequate feedback and support and also felt a heightened sense of motivation. Furthermore, the tutorial sessions proved to be highly beneficial in aiding students' comprehension of fundamental concepts needed for project execution, and students also reported that they gained a solid understanding of the theoretical concepts and practical steps involved in cloning strategies (Figure 1 (II)). Additionally, students acquired more autonomy and confidence in carrying out laboratory work and reported that it was very productive to have applied the project developed in the practical classes and that the accomplishment of the laboratory work was easier than if they were given a protocol (Figure 1 (III)). The students identified that implementing this methodology required more study and work compared to traditional protocols, which was the only less positive aspect they mentioned. However, the two curricular units have taken into account the amount of autonomous work and research required to ensure that the necessary hours of work for this project were adequately covered.

Figure 1

The evaluation of the Problem-Based Learning approach data categorised under three topics: Global satisfaction (I), Knowledge acquisition (II), and PBL vs. Traditional methodology (III)





4. Final considerations

Genetic Engineering is a complex field that encompasses various disciplines such as molecular biology, genetics, biochemistry, and biotechnology. Typically, it is taught through a combination of theoretical and laboratory classes. However, it has been observed that many students tend to memorize concepts and perform laboratory tasks without developing a comprehensive understanding of the process.

The implementation of a student-centred cloning strategies learning project has yielded positive results. Based on the feedback from the students, this pedagogical approach has been effective in promoting cognitive development, enhancing motivation, and fostering a sense of responsibility. Moreover, the students reported a better understanding of cloning concepts and strategies and perceived the methodology to be beneficial. Therefore, Project-Based Learning (PBL) appears to be suitable for future teaching endeavours in this field.

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