Inquiry Based Learning in practice to enhance an Immunological Biotechnologies laboratory experience

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Abstract
This paper aims to describe a teaching redesign experience that took place through the introduction of the Inquiry Based Learning methodology within the course of Immunological Biotechnology included in the program of the Master's Degree in Industrial Biotechnologies at the University of Padua. The decision to introduce this approach starts from the need to maximise and support students during the learning experience, to sustain the development of specific skills related to real-world laboratory research environments, making them more aware of the design and practical steps of the laboratory itself. The new design (and its implementation) has both enhanced student learning and improved satisfaction with the teaching. The feedback from the students also allowed us to acquire important information to work further on teaching and create more authentic and effective experiences, through a teaching and learning approach based on investigation.
Key words: Inquiry Based Learning, teaching-learning design, laboratory experience, research competences, technologies for education.

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1. Introduction and reasons for the experience

1.1 The Inquiry Based Learning methodology and implementation

The Inquiry Based Learning (IBL) approach envisages a design based on the inquiry-based teaching approach, intended as "a technique that encourages students to discover or construct information by themselves instead of having teachers directly reveal the information" (Uno, 1999; Duran & Duran, 2004, p.49)", so "an educational strategy in which students follow methods and practices similar to those of professional scientists to construct knowledge" (Keselman, 2003; Pedaste et al., 2015, p.48).

One of the most popular approaches for designing IBL experience is the 5E Instructional Model (Bybee & Landes, 1990) based upon cognitive psychology, constructivist-learning theory (Bruner, 1990), and best practices in science teaching.

The design and the implementation process are composed by the following steps:

- Engagement: assessment of student's prior knowledge and/or identification of possible misconceptions. Motivational phase that supports the desire to actively explore the topic further, through a concrete learning experience.
- Exploration: students are encouraged to actively apply skills such as observing, questioning, investigating, testing predictions, hypothesising and communicating with other peers, supported by the teacher as facilitator.
- Explanation: students describe their understanding and ask questions about the concepts explored. Subsequently, the teacher introduces scientific and technical information in a direct manner, including the use of interactive resources, clarifying doubts raised during the previous phases.
- Elaboration: students are encouraged to apply their new understanding, reinforcing new skills and to compare themselves with their peers, design new experiments or models and carry out further investigations.
- Evaluation: assessment as a continuous process in which teachers observe students as they apply new concepts and skills. Observation may be accompanied by self- or peer-assessment experiences and may also include a summative experience (quiz, exam or writing assignment) (Duran & Duran, 2006).

This methodology is characterised by a process of students discovering new causal relations, through the formulation of hypotheses, the relative testing process by conducting experiments and/or making observations (Pedaste et al., 2012; National Research Council (NRC) Standards, 1996) and it is sustained by the 'learning by doing' perspective (Dewey, 1933; Spronken-Smith, 2012).

IBL is comprehended in the student-centred approaches (Kember, 1997; Archer-Kuhn et al., 2020) so an active learning methodology that sustains the development of self-directed learning skills: the strategy promotes the vision of students as direct creators and builders of their own knowledge, also with the implications of collaborative way of learning through work group activities (Kember, 1997; Gibbs, 1988, Healey & Roberts, 2004).

The methodology could be useful to stimulate the development of specific skills like problem solving and critical thinking (Pedaste & Sarapuu, 2006; Thaiposri & Wannapiroon, 2015): its implementation can in fact "emphasises active participation and learner's responsibility for discovering knowledge that is new to the learner" (de Jong & van Joolingen, 1998, Pedaste et al., 2015, p.48). The teachers' role is to guide the inquiry process as facilitator of learning for students: in fact, as the literature points out, empirical research on inquiry learning sustains that delivering specific assistance during the inquiry activity - such as feedback, worked examples, elicitation of explanations - benefits learners and improves learning outcomes achievement (Alfieri et al. 2011; Lehtinen & Viiri, 2017).

In order to structure the IBL experience Banchi & Bell (2008) theorised different levels of complexity: in fact, they found a four-level continuum useful to classify the levels of inquiry in a specific teaching and learning activity.

- Confirmation Inquiry: students acquire the research questions and the process and results are made available a priori. Then the whole process is made available to the students who must then confirm it through an investigation process.
- Structured Inquiry: teachers offer to students the research questions and process, but the data collection and the results analysis are connected to the specific action of students themselves.
- Guided Inquiry: determination of the research problem/question, leaving freedom of investigation and analysis to the learners who, through their own knowledge and research, will extrapolate from the problem the process of performing the method and establish the results.
- Open Inquiry or Project Work: it is defined as pure inquiry. When the students are high-skilled, in fact everything is designed by them and the teacher plays the role of facilitator of learning during the investigation and design process.

1.2 The course of Immunological Biotechnologies

Demaria, Barry & Murphy (2019) show the complexity in teaching immunology in the undergraduate laboratory: in fact, "it requires background knowledge, data analysis skills, critical thinking, and design capacities to include relevant controls and applications of particular techniques to answer a research question. It also requires strong technical skills" (p.1). Teaching process in courses with practical laboratory could be structured combining traditional teaching strategies to scaffold students learning on basic fundamental disciplinary techniques, but to support the development of the specific technical skills, it is important to move from the recipe-based approach to a more interactive modality of teaching (Demaria et al., 2019).

In connection with our formative design context, the IBL activity was implemented in a course named Immunological Biotechnologies, a second-year course of the Master Degree in Industrial Biotechnologies (University of Padova). Immunological Biotechnologies course includes frontal lectures (32 hours) and a practical activity held in the didactical laboratories (32 hours). The main topic of the course is how a vaccine, both preventive and therapeutic, is developed; the practical activity simulates how a therapeutic vaccine could be produced in laboratory; students work in pairs and they learn how to handle primary human immune cells in sterility conditions, how to evaluate their responses in vitro, how to perform complex immunology experimental protocols (ELISA, western blot, flow cytometry), and how to analyse data and draw proper conclusions from them. The practical experience requires ten days, during which the students are in the laboratory about 4 hours a day. During the final exam, students must answer a 30-question quiz about the practical activity, which includes different types of questions about the methodologies and the protocols used during the laboratory.

1.3 Research aim

The main aim of the research is to understand if:

1. The introduction of a specific teaching methodology, like in this case the IBL approach, could be useful to sustain students' engagement during the learning process.
2. The IBL can scaffold the students' major awareness about laboratory processes.
3. It helps the improvement of the final exam performance. Furthermore, the IBL methodology will be adopted to stimulate the acquisition of specific competencies, like critical thinking and problem solving.

In fact, the results of the final quiz in previous years were not satisfactory. Moreover, although the students were able to follow very detailed protocols, the workflow, which is intended to mimic what happens in a real research laboratory, was not clear to the majority of students. For these reasons, we decided to introduce this kind of activity, just before the beginning of the laboratory, to help students to become more aware of the practical steps of the laboratory and also to help them to better understand how to plan a research experience. In the literature, there are many examples where the IBL has been introduced in preparation for a laboratory activity, not only in the field of immunology (Demaria et al., 2019) but also in other study programs where laboratories are fundamental (Parappilly et al., 2013; Lents, Cifuentes & Carpi, 2010; Wiseman et al., 2020). All of them highlight how the transition from a laboratory activity based on standardised protocols – which students follow without any involvement – to an IBL-activity allows students to use their prior knowledge and critical reasoning. In fact, IBL-activity design can be crucial to sustain an engaging teaching and learning process and to stimulate the development of specific disciplinary competences in an interactive way.

To structure the experience, the IBL-activity was designed based on the guided level, to prompt the reflection on how to construct a research activity starting from a scientific question. Additionally, through the IBL-activity, students were guided in the use of laboratory protocols by reasoning through the steps of the laboratory techniques before implementing them.

The IBL-activity aimed therefore to enhance the following specific skills:

1. Proactive review of concepts learned in other courses, interconnected with the new topics;
2. Reflecting on the process of planning a research activity;
3. Reflecting on the correct order of the various phases of a laboratory assay;
4. How and where to search for information on laboratory protocols relevant to a specific task;
5. Reflecting on the importance of choosing positive and negative controls in a scientific experiment.

2. Description of the Methodology

The IBL-activity lasted for 5 hours and was conducted one week before the beginning of the practical activity. Through open-ended questions, short bibliographic research, multiple-choice questions, word clouds, label an image, and the "sorting" activity, students, working in groups, were guided to:

- Understand the connection between theoretical lectures and the practical laboratory activity Reflect about choosing experimental techniques, based on the research goal.
- Reflect on the different phases involved in the laboratory work.
- Conduct bibliographic research on methods used in laboratory for a specific purpose.
- Consider the concepts of negative and positive controls, essential when performing experiments in laboratory.

- Reflect on the appropriate methodology to analyse experiments.
- Reflect about the correct sequence of steps of a particular technique.
- Bring out knowledge acquired from previous courses that had not been put into practice.

During the IBL-activity the following activities were included:
- Engagement activities to present the various laboratory assays and the “experimental problem”.
- Exploration activities by means of bibliographic research and consolidation of prior knowledge.
- Explanation and Debriefing phases to discuss the answers from different groups and to provide further details on the experimental activity.

After the actual IBL session, these activities were also implemented:
- Elaboration activities during which students generated experimental data, analysed and discussed the results, and recorded them in their laboratory notebooks.
- Evaluation phases by means of feedback modules, a midway evaluative quiz with Wooclap and a Moodle quiz one week after the end of the laboratory activity.

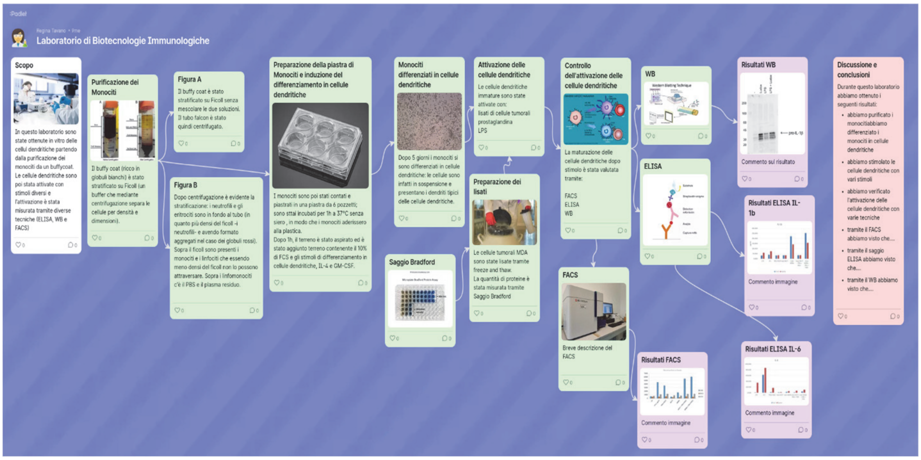
The IBL-activity was entirely conducted using the student response system Wooclap, integrating slides with explanations, debriefing moments and different kinds of questions. Wooclap was also used to collect final feedback on the level of student engagement during IBL, and to gather ideas and suggestions for further implementation. This aimed to assess the students' perception of satisfaction and usefulness of the activity.

To help students in the learning process of the numerous concepts and techniques, they were asked to complete a predefined form at the end of each laboratory day, mimicking a true laboratory notebook. The form was created in the Moodle “database” activity and students were required to include the following information:
- Experiment date;
- Objective of the laboratory session;
- Materials/methods/tools used;
- Descriptive list of the steps performed;
- Results obtained;
- Self-evaluation (description of difficulties encountered with the protocol and particularly successful steps).

At the midpoint of the laboratory experience, a short group challenge was introduced using Wooclap, to give the students the opportunity to assess how much they had learned and understood about the practical activity. At the end, a ranking was created, and bonus points were awarded to the top three groups, which were included in the final evaluation.

With the purpose of guiding students in the learning process and making them reflect on the flow of the practical experience (scientific question, methodologies, and assays used to answer the scientific question, data analysis, and interpretation), each group was assigned to create a summary with Padlet, a software useful to the creation of multimedia boards, similar to the one shown in Figure 1.

Figure 1 – Example of Padlet application for visualising the workflow during the practical laboratory



Eventually, at the end of the practical laboratory, students were asked to fill out a feedback form, aimed to evaluate the satisfaction and usefulness of the laboratory experience. The same module had been used in the previous academic year (a.y.), allowing for an assessment of the effectiveness of the inclusion of the IBL-activity.

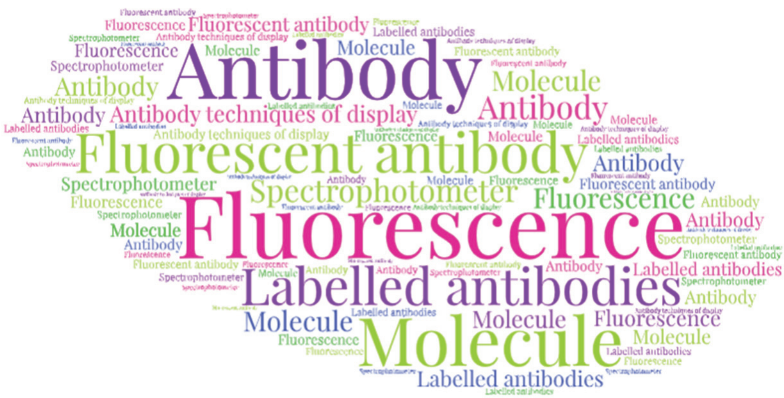
3. Results

3.1 Findings and Feedback on the IBL-activity

Out of the 35 students attending the course of Immunological Biotechnologies, 33 students were present on the days when the IBL-activity was conducted. Four students were unable to respond due to connection issues, so the results of the activity were evaluated based on the responses of 29 students.

The results of the word clouds, used to assess prior knowledge, generated interest and sometimes led to discussions and debates among students and the instructor, as well as between student groups. An example of a word cloud created in class is provided (Figure 2).

Figure 2 - Example of a word cloud built with students' responses



The word clouds, used to gather information after a bibliographic search, allowed for an engaging introduction to the topic. Questions that required ordering the phases of the laboratory or the steps of a particular technique proved to be the most challenging. At the end of the two IBL sessions, students were asked to provide anonymous feedback on various aspects (engagement, usefulness, interest, time spent, and clarity of the experience's main thread), rating them on a scale from 1 (not at all) to 5 (extremely). The results, presented in Figure 3, represent the averages of the responses; the average rating for all evaluated parameters settled at Figure 4.

Figure 3 - Average results (29 students responding out of 35 attending) of satisfaction with the IBL-activity: the parameters evaluated were rated on a scale from 1 (not at all) to 5 (extremely)

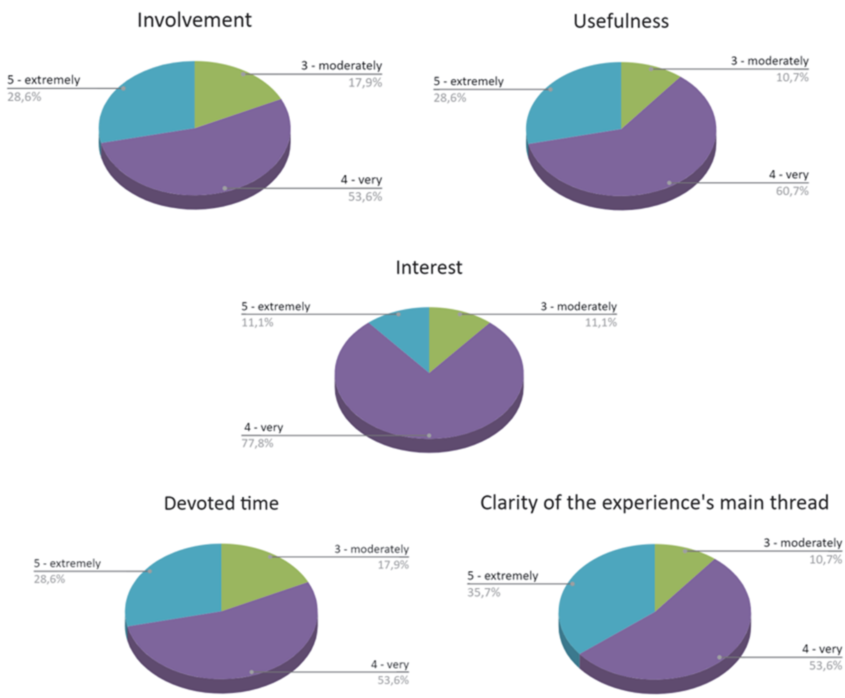
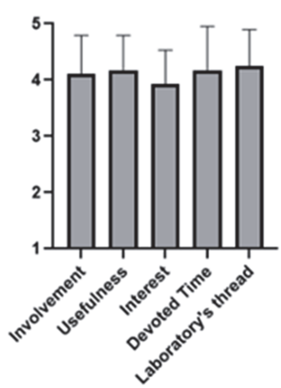


Figure 4 - Percentages of student responses about the satisfaction with the IBL-activity: the parameters evaluated were rated on a scale from 1 (not at all) to 5 (extremely)



Students were also asked to share the most important thing they learned and to provide suggestions, ideas, and observations on the IBL-activity. Here are some of their responses (Table 1).

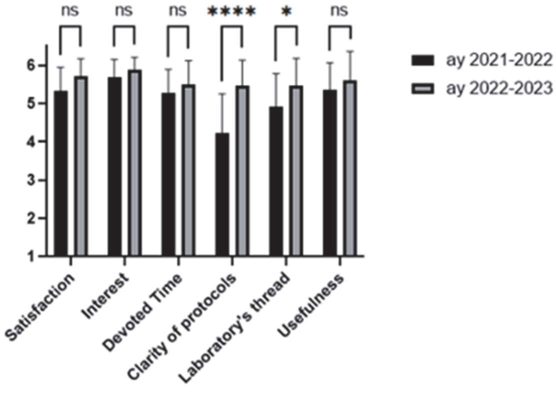
Table 1 - Students' testimony of learning and point of view on IBL experience

Students' testimony of learning	Students' point of view on IBL experience
• "How to carry out laboratory activities" • "Active search for informations" • "Features of different analysis techniques • "The importance of reviewing previously used techniques and organising ideas before implementation" • "Logical/methodical organisation of experiments"	• "A Kahoot game at the end of the lesson would be fun and bring some healthy competition" • "It's perfect as it is!" • "It would be helpful to have a final recap of the logical thread" • "Videos would be useful" • "It was helpful; it should be continued" • "Active involvement was useful for better understanding of concepts" • "Reduce the number of protocols to be ordered"

3.2 Comparison of overall satisfaction for the laboratory activity in the 2021/2022 and 2022/2023 a.y.

At the end of the practical activity, an additional feedback form was submitted to the students to assess their satisfaction. The module consisted of a series of questions to which students could rate their responses on a scale from 1 (not at all) to 6 (extremely). All 35 attending students responded to the feedback activity. The same module had been already used in the previous a.y., where there were 25 attending and responding students. Figure 5 represents the results.

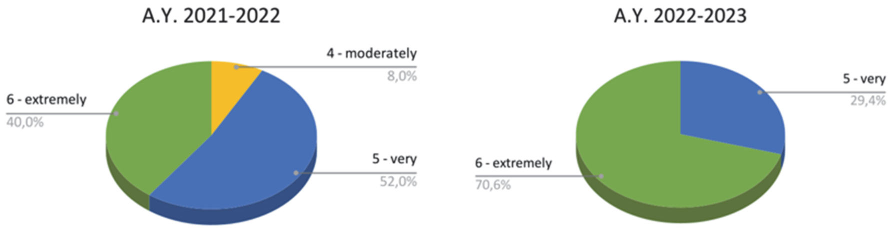
Figure 5 - Comparison of average ratings of satisfaction with the laboratory activity in the 2021/2022 a.y and the 2022/2023 a.y.



*Note: In 2022/2023 a.y the IBL-activity was introduced and there were 35 attending students, in the 2021/2022 a.y. there were 25 attending students. The parameters evaluated were rated on a scale from 1 (not at all) to 6 (extremely). ns: not significant, * p < 0.1, **** p < 0.0001, calculated using a two-way ANOVA test.*

Regarding overall satisfaction, the percentages of ratings given by students are also shown in Figure 6.

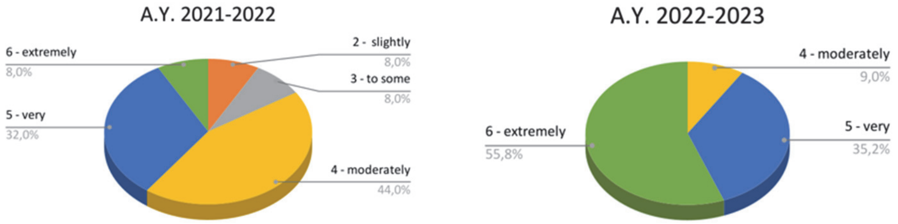
Figure 6 - Perceived level of satisfaction by the students in the 2021/2022 a.y and the 2022/2023 a.y.



Note: Percentages of student responses on a scale from 1 (not at all) to 6 (extremely) to the question regarding satisfaction about the laboratory activity; comparison between the two a.y. under study (25 students for the 2021/2022 a.y., 35 students for the 2022/2023 a.y.).

In Figure 7 a significant difference is evident in terms of protocol clarity. The handouts provided to students, containing the description of all the steps of the practical activity, were identical in both a.y. The percentages of ratings given by students for this aspect are shown in Figure 7.

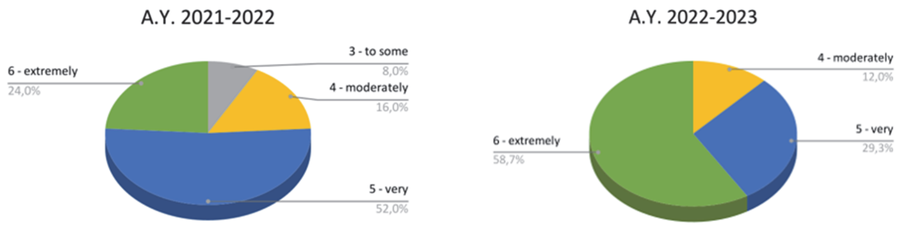
Figure 7. Perceived level of clarity of the protocols by the students in the 2021/2022 a.y and the 2022/2023 a.y.



Note: Percentages of student responses on a scale from 1 (not at all) to 6 (extremely) to the question regarding the clarity of the provided protocols; comparison between the two a.y. under study.

In terms of clarity of the laboratory's main thread, here below the graphs represent the extrapolated data referred to this area of analysis (see Figure 8).

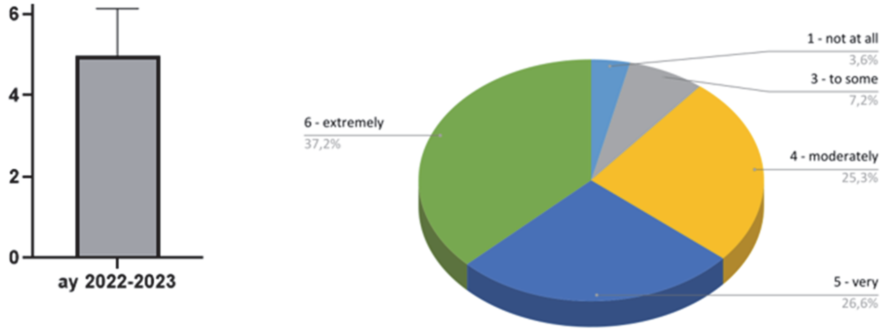
Figure 8 - Clarity of the laboratory experience's main thread



Note: Percentages of student responses on a scale from 1 (not at all) to 6 (extremely) to the question regarding the clarity of the laboratory experience's main thread; comparison between the two a.y. under study.

At the end of the practical activity, students were also asked to assess the usefulness of the IBL-activity in preparing them for the various laboratory activities. Figure 9 shows the average satisfaction ratings obtained on a scale from 1 to 6 (left panel) and the percentages of student responses (right panel).

Figure 9 - Usefulness of the IBL-activity perceived by the students



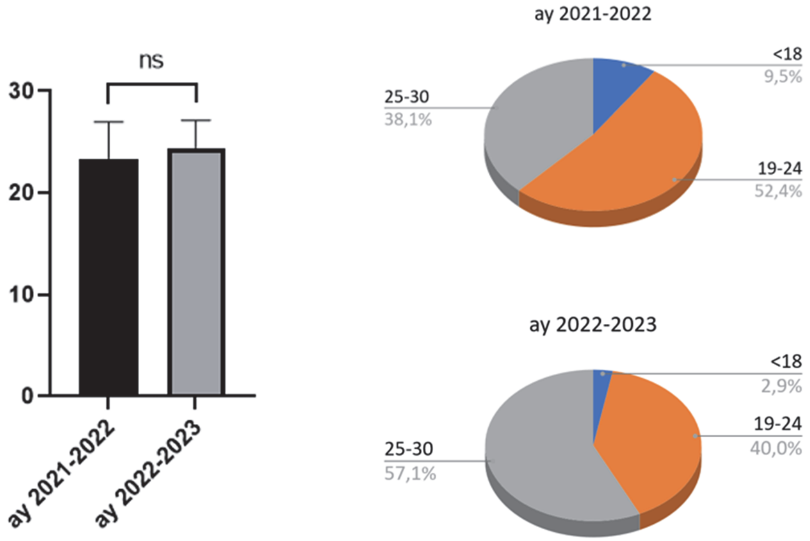
Note: data (average ratings on a scale from 1-not at all to 6-extremely) on the right and percentages of responses on the left on the perceived usefulness of the IBL-activity by students (35 answers).

3.3 Comparison of Final Exam Results for the 2021/2022 and 2022/2023 a.y.

During the 2022-2023 a.y. a challenge, aimed to assess their understanding of the techniques and to identify any critical points, was introduced midway through the laboratory experience. Students, divided into groups, had to answer ten questions related to the techniques they had used up to that point. The average of correct answers was 71.4%; the results were discussed and additional explanations were provided to students regarding critical questions.

In the 2022-2023 a.y., a change was also made to the final exam. The laboratory quiz was scheduled not at the end of the semester but two weeks after the end of the practical activities. The following figure (Fig. 10) displays in the left panel the overall average scores (0-30 scale) obtained by students in the laboratory quiz in the right panel the percentages of the range scores achieved by the students in the two a.y. analysed.

Fig. 10 - Data on student assessment after the final quiz



Note: On the left panel, the averages of the results obtained in the same type of quiz by students from the two a.y. under examination are represented. On the right panel, comparison of the percentages of students who achieved different range scores (<18/30, 19-24/30, 25-30/30) in the two a.y. under examination.

In terms of students' percentage who took the exam in the first session, in the 2021-2022 a.y., 16% of enrolled students took the exam in the first session, while in the 2022-2023 a.y., the students' percentage was 54.3%. After the second session, the percentage rose to 44% in the 2021-2022 a.y. and to 71.4% in the 2022-2023 a.y.

4. Discussion

4.1 Students' feedback on the IBL-activity

From the analysis process of the 29 students' responses emerged interesting data connected to the IBL-activity feedback.

The world cloud activities created to collect data in terms of prior knowledge demonstrate the possibility to integrate interactive moments, among students and with the teacher.

The activities designed to stimulate the reflection on the phases connected to the laboratory procedure underlined the difficulty for students to focus on the main steps regarding the practical activity: the low rate of success (25% correct responses), in fact, shows that this reflection activity could be powerful to put the basis of specific formative steps to sustain student scientific literacy (Keselman, 2003; Pedaste et al., 2015).

In terms of students' feedback, the data gathered put in evidence that in general the students declared to be very engaged during the inquiry process (53.6%). The perception of usefulness of the activity was evaluated by the majority of students as really useful (60.7%) and in general the interest was very high (scale point 4; 77.8%). In terms of devoted time spent on the IBL-activity and the related clarity of the whole process, students were very satisfied (scale point 4 - 53.6%). They were asked to rate these aspects on a scale from 1 (not at all) to 5 (extremely). It's important to affirm that in general, the IBL-activity was really appreciated both in terms of the organisation of the experience and in relation to the engagement with respect to the teaching and learning process, which is therefore powerful, effective and student centred (Kember, 1997).

4.2 Comparison of overall satisfaction for the laboratory activity in the 2021/2022 and 2022/2023 a.y.

The analysis, connected to the satisfaction of the laboratory activity and the related comparison between the results of the 2021/2022 and 2022/2023 a.y., put in evidence interesting data to inform a complex overview of the experience.

The assessment criteria used to explore the impact allowed us to better investigate the students' perceptions: one particularly interesting result is the percentage of students who gave the highest rating, which increased from 40% to 71%.

In terms of general satisfaction, the average rating increased meaningfully:

in fact, in relation to the 2022-2023 a.y. students are extremely satisfied (70.6%) and very satisfied (29.4%), in contrast with the previous a.y. when students' perception is divided between moderately (8%), very (52%) and extremely satisfied with the laboratory experience (40%).

Also, in relation with the areas connected to the interest and the devoted time, it seems that the total average has slightly increased.

The students' perception of protocol clarity significantly improved after the introduction of the IBL-activity (**** $p < 0.0001$) compared to the previous year. The percentage of students who considered the protocols to be very clear increased from 8% to 56%; the percentage of students rating the clarity of the protocols as 4 decreased from 44% to 9%. The clarity of the laboratory experience's main thread also significantly increased (* $p < 0.1$), furthermore after the introduction of the activity, the percentage of students who gave the highest rating to this parameter increased from 24% to 56%.

Approximately 90% of students rated the usefulness of the IBL-activity higher than 4.

To conclude, the laboratory experience proposed this year established an improved experience for the students, who perceived the usefulness of the activities in connection with the specificity of the teaching course, related contents and connected competences.

4.3 Comparison of Final Exam Results for the 2021/2022 and 2022/2023 a.y.

The middle challenge experience highlights the power of introducing stimulating activities to sustain reflection and self-assessment processes during the learning path of the students. In fact, this activity seems to be powerful to monitor the learning progress both from the point of view of students and of the teacher, who has been able to acquire important data to support a continuous redesign of his/her teaching and support the learning experience. The gamification process appears to be important to sustain the formative assessment process embedded during the IBL laboratory module (Demaria et al., 2019).

The final quiz average score did not show a significant change in the two analysed a.y. and the percentage of correct answers given by students only increased from 74% to 78.4%. However, what is particularly interesting is the increase in the percentage of students who achieved a score higher than 25/30 on the exam, which rose from 38.1% in the 2021-2022 a.y. to 57.1% in the 2022-2023 a.y.. Furthermore, the percentage of students who took the exam in the first session has increased by more than three times in the two a.y. under consideration. The data show that, through the direct support of self-directed learning skills (Bruner, 1990) and specific knowledge and competences promoted by the IBL methodology, students seem to be more self-confident for the final examination and this allows the students themselves to feel effective in their preparation so as to participate in the first exam attempt. Despite the small sample size, it is evident that the IBL methodology may be a valuable support in supporting the development of specific STEM competences, such as the ability to work in teams, the development of critical thinking with respect to practical laboratory activities, and the acquisition of skills related to the exploration and solving of concrete problems in disciplinary practice (Demaria, Barry & Murphy, 2019).

5. Conclusions and future perspectives

In general, the experience structured following the guided level of the Inquiry Based Learning (Banchi & Bell, 2008) and designed through the 5E model (Pedaste et al., 2015), seems to sustain a real process of active learning (Archer-Kuhn et al., 2020), with a learning by doing philosophy (Gibbs, 1988, Healey & Roberts, 2004) and a student-centred approach (Kember, 1997).

Also, if the number of students was not wide, it is possible to affirm that, in connection with the research question n° 1 dedicated to the engagement improvement, the structure of the activity stimulates students' involvement in class, sustaining and increasing the general satisfaction and also the perception of usefulness and related interest. In terms of the awareness improvement, the clarity of the laboratory experience increased after the IBL-activity and students perceived scaffolding in preparing them for the various laboratory activities thanks to the adoption of this approach.

Finally, in relation to the students' final performance, it was not a significant statistical difference regarding the final assessment grades.

In terms of research limitations, after the analysis of the data it is possible to affirm that it could be important to increase the time dedicated to the IBL-activity to maximise an effective support of students during the formative experience.

As a final limitation connected to the results of the IBL-activity and in direct connection with the not statistically significant comparison of the final exam results, the main issue could be related to the fact that the cohorts analysed are different. This statement means that students have different characteristics than variables that may affect experience and final assessment average are multiple, complex and can influence the assessment of the overall impact of IBL-activity. For this reason, it will be important to include an initial pre-test in the next a.y., to assess the students' prior knowledge and to scaffold the activities' design and the implementation.

Below, some future research perspectives will be described.

First of all, starting from a careful study of the results of the laboratory quiz, it will be essential to identify the weak points, possibly reformulate the questions and review the experience to implement these shortcomings. For this, it could be important to introduce a small IBL-activity at the beginning of each laboratory day (for example, tidying up the work phases of that particular day) to support the development of critical thinking skills in the personal discovery and deeper understanding of the inquiry learning process (Archer-Kuhn, B. et. al, 2020).

Furthermore, at the end of the IBL-activity and before the practical laboratory could be interesting to ask students to create a Padlet in which they hypothesise the workflow of experimentation to push the activity of IBL even more towards an open investigation.

Finally, at the end of the laboratory, it should be important to organise a meeting at which all the groups present their data and a related debate activity in plenary on the results obtained. This process will be crucial to sustain a debriefing moment and to create a discussion flow to explore the aspects that have (or have not) worked.

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