Formative Assessment and Professional Training: Reflections from a Mathematics course in Bioengineering

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Abstract. Bioengineering is currently considered an interdisciplinary professional field which provides solutions to different problems arising in the area of health care. Its strategic importance is widely acknowledged since its developments and proposals could help diminish the level of technological dependence in the sector. The fast pace of innovation in the area of biomedical technology gives rise to permanent reflection on the learning goals and teaching strategies proposed by educators in the different training stages of a bioengineer. In this context, learning assessment appears as a controversial issue which needs to be debated and rethought. This paper describes the reflections of teachers of a Mathematics course within a Bioengineering program around the question, What approach to assessment favors the student's participation, autonomy and training as a future bioengineer? The investigation was carried out in the framework of a Participatory Research Action project and helped us to redesign assessment activities from a different perspective.

1. Introduction

While the universe of scientific and technological advances related to a bioengineer's job changes rapidly and the dynamics of this system is perceived as dramatic and challenging, the academic world in which such a professional is trained seems to cling to old traditions. This is more conspicuously perceived in the assessment process, especially in the first years of the program which are dominated by basic disciplines, in which tests (be they midterm or final) in their different formats are firmly entrenched and seem to mark the pace of the courses, especially those of Mathematics. This is at least our perception as teachers of the Department of Mathematics at the Engineering School of the National University of Entre Ríos. A first disruption of the assessment system was observed when computer technology arrived to the University and the Engineering Schools incorporated Computer Science Laboratories; little by little, assignments completed with specific software gained an increasing space in the planning of Mathematics courses, although they did not displace midterm tests or match their importance.

While it seems natural to question the currency and training value of the contents we teach, reflecting on the assessment methodology we implement in our courses and its relationship with the training of the future bioengineer leads us to uncharted territory we are apprehensive to step into. When we take courage and ask ourselves, “What to assess?,” a series of questions arise that little by little unveil the complexity of assessment: How?, When?, For what?, For whom?, Whom does it benefit?, What’s the goal?, In what context?

Students, on their part, make queries from the beginning about the assessment system and understandably ask: “How many midterm tests?”, “What are they like?”, “What topics do they cover?”, “How much time are we given to solve them?”, “What support can we use?”. They also devote much time to collecting tests from past courses and in many cases this material replaces textbooks, teacher-prepared slides and guides, and their own in-class output. In this scheme they would seem to develop skills for academic life, focusing their efforts on getting the necessary grade to attain the status of regular or promoted students, pushing learning into the background.

We ask ourselves then, how does our assessment style influence our students’ learning? Is it consistent with the course’s aims? Is it aligned with teaching strategies? Does it contribute to the development of critical thought, or does it favor learning by heart? Does it foster the necessary abilities to complete undergraduate training in Bioengineering? Does it strengthen the skills necessary to enter professional practice? The question list seems endless and even then we are neglecting a fundamental question: What do we understand by assessment? That could be the starting point for unraveling a thread from which we can get the answers sought.

In this work we describe a portion of the exploratory path we have trodden in our activity as Mathematics teachers from the courses of Vector Calculus and Differential Equations at the Bioengineering program. We wish to highlight that our team is interdisciplinary as it is made up of an Electrical Engineer (the Professor in charge of the courses), a Professor of Mathematics (the Associate Professor of the courses), a Chemical Engineer (one of the Practical Applications Teachers), three young Bioengineers who beside working as Practical Applications Teachers at the Department of Mathematics are completing their postgraduate studies in different specializations of Bioengineering, two advanced Bioengineering students, a teacher from the Department of Humanities and the Pedagogical Advisor of the School of Engineering, who holds a BA in Education Science. This investigation is framed in the methodological principles of Action-Research. In the following sections we will describe this methodology and how study and research seminars helped us construct a theoretical framework of reference that allowed us to find new meanings and approaches to assessment which favor student participation, their autonomy and their training as future bioengineers.

2. –The methodology: Action-Research

Various works published in the fields of Psychology, Social Psychology, Education in general and Health-Care Education in particular state that the term, “Action-Research,” was first defined by Kurt Lewin, who carried out studies on rural medicine, biology and philosophy in Germany. At the onset of religious persecution in that country he decided to move, in 1933, to the United States. He worked at the Massachussets Institute of Technology, where he established the Center for Group Dynamics. The literature recognizes that the first Action-Research process took place in the 1940s when Lewin took on an urgent challenge: that of introducing changes into the feeding habits of a population affected by the scarcity of certain products in the context of World War Two. After different experiences, Lewin concluded that better results are obtained when the community or group of people affected by the problem are incorporated into the quest for solutions and their implementation.

In the educational field, these ideas were revisited and reassessed in the 1970s by UK pedagogists Lawrence Stenhouse and John Elliot, who picked up Lewin’s model. To these educators, Action-

Research (AR) relates to practical, everyday problems experienced by teachers. Elliot posits that AR solves the problem of the relationship between theory and practice since it enables the teacher to problematize, analize and propose improvements from and for their own day to day practice. That is to say that the teachers undertake a researcher's role as s/he systematically plans, acts, observes, reflects and inquiries into her/his teaching practice to produce knowledge and changes aiming to improve it [1].

With regard to the research process, this is structured in cycles, each of which includes four phases or moments: (1) phase of diagnosis and INITIAL REFLECTION, which helps identify "problematic" situations and establish priorities; (2) phase of reviewing the conceptual framework and PLANNING an improvement or innovation; (3) phase of implementation of the planned ACTION; and (4) phase of observation and appraisal of results. At this point, a new instance of reflection starts a second research cycle. A review of the theoretical framework and of the knowledge acquired in practice will allow actions to be redesigned so as to move forward with the process [2].

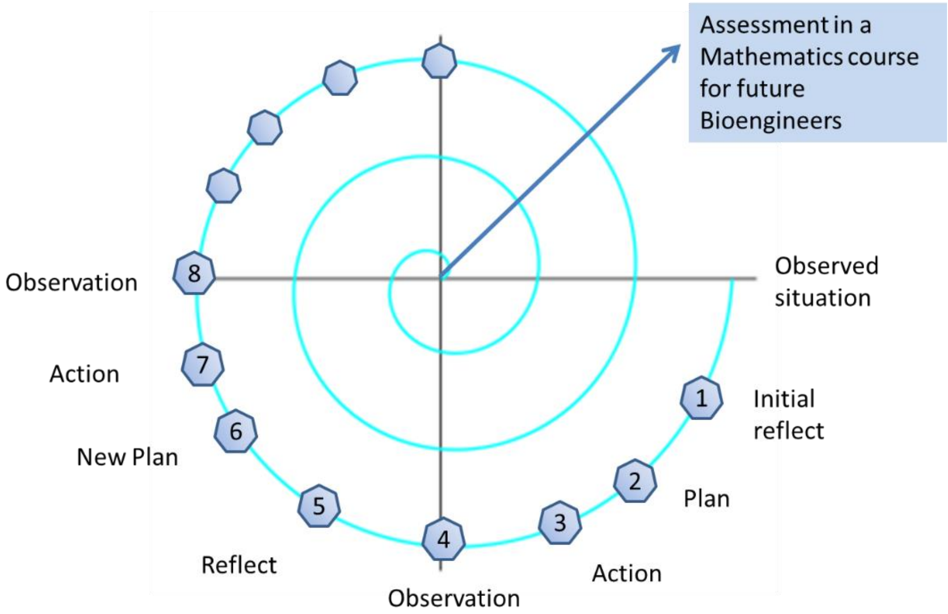

Figure 1. Illustrates the phases of the Action-Research process. During it and little by little, cycle after cycle the participating teachers-researchers uncover different aspects and strive to understand the outcome of the assessment methodology applied, detecting unsatisfactory aspects and preparing new action plans that allow assessment to be oriented towards a formative approach at the service of learning.

This methodology combines three processes, those of knowing, acting and teaching, all of which involve the whole academic community that participates. It aims to construct knowledge that will bring about a change in those aspects of educational practice that emerge during the research as possible hindrances to learning.

In our case we have started a spiral process (Figure 1) with the aim to investigate assessment in the mentioned courses to understand it deeply and detect aspects that might be negatively influencing the learning process so as to improve them.

Our *Collaborative Work Seminar* is an integral part of the process. Through teamwork, which fosters and encourages each participant's reflection, we started to analyze learning assessment in the courses we teach. In our project the *Seminar* constitutes an environment of study, investigation and shared decision making affecting the different research stages. Through it each participating teacher gets a deeper grasp of the theoretical and practical skills that allow them to research into the problem in the context of their own teaching practice to better understand it and propose mechanisms for improvement and transformation.

In the next section, we briefly describe the theoretical framework of reference collaboratively constructed by the participating teachers.

3. The construction of the theoretical framework of reference

The questions posed in the introduction oriented the literature review. Reading and discussing different materials allowed us to discover various approaches and perspectives that have enriched our conception of assessment. After the extensive analysis done, we prepared a synopsis of the situations described by different authors and selected certain conceptual guidelines.

The meaning of assessment in the educational field has changed over time, shaped by social, economic and political situations, as well as by scientific and technological advances [3].

In higher-level institutions where professionals are trained, such as Engineering schools, the assessment process has both a formative and a certifying function [4], [5]. From a formative viewpoint, assessment can be understood as the window through which teachers and students get information on the progress of the teaching and learning processes. Based on what they observe, teachers introduce changes or new activities while students modify their studying strategies so as to bridge the gap between the reality observed and the objectives of the course or program.

From a certification viewpoint, assessment is a process oriented towards ensuring that students have acquired the basic skills and knowledge to move forward in the program, so that upon ending his or her studies the new graduate has the abilities required to enter professional life. From a conceptual viewpoint and in teaching tradition, this kind of assessment is called Summative or Accumulative Assessment, and its results are used to decide grades or student promotion at course end.

In both the international and national contexts, we find a wealth of research and documents describing unbalances or pathologies in the assessment process in higher learning. They highlight that the certifying function is often privileged over the formative one, and assessment is not usually interpreted in a wider, more open sense, but as a synonym of grading or other terms such as marks, exam, test, control among others [6],[7]. Assessment is done only at the end of each period and simply to test the level of "learning" achieved. Thus, assessment only affects the student and has a belated and scarcely relevant influence on the learning process.

In the last few years and in an international context, a move to extend the meaning of assessment in higher learning can be observed, aiming to enhance its function as a promoter of learning. In education science papers different terms have arisen which are closely related to this function of assessment: Formative Assessment, Alternative Assessment, True Assessment, Assessment for Learning, Forming Assessment, Learning-Oriented Assessment.

The theoretical principles of Formative Assessment are found in the works of Sadler, Black and Wiliam [8], [9]. These authors defined formative assessment as that comprising "all those activities undertaken by teachers, and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged" (1998: 7). This definition helps to identify the three essential aspects of Formative Assessment indicated in Figure 2:

- The precise communication of the objective to be met, that is to say, clear indications to the student about the goal or expected learning and about the criteria that will be used to assess their work.
- Information on the student's current situation with regard to the proposed goal, be it through teacher feedback or through self-assessment, so that the students can know their starting point before undertaking a new effort and continuing their learning process.
- Improvement strategies and student orientation as needed so that they will be able to advance, overcome difficulties and get closer to the goal.
- Following these conceptual guidelines, a new assessment plan for the Vector Calculus and Differential Equation courses was prepared. This is described in the following sections.

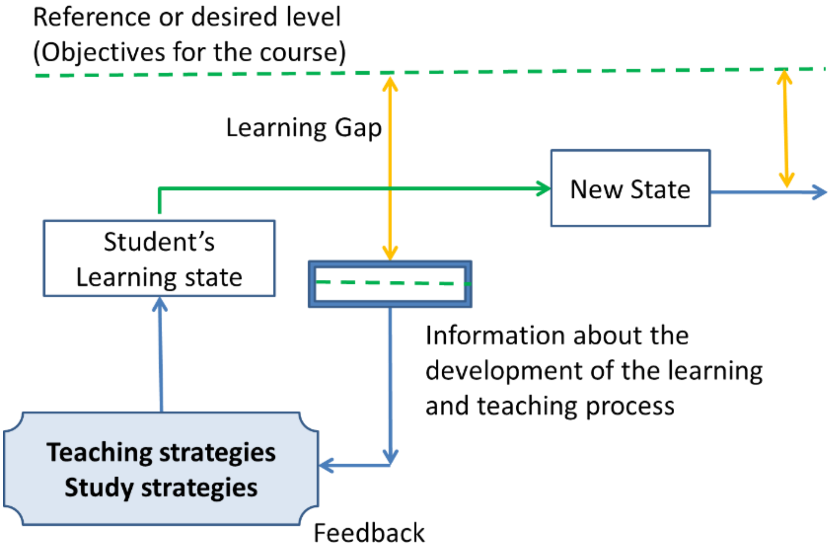

Figure 2: Illustrates the different stages of Formative Assessment; their results provide information to improve the system.

4. Assessment Process Planning

Analysis of the course objectives

From the conceptual reference framework considered, the design of a new assessment plan begins with an explicit statement of the course objectives. A document analysis was carried out to orient the updating and redesign of objectives so that they would become consistent and aligned with the Professional Profile, the current job market and the future prospects of the program. To achieve this, we reviewed the guidelines set by Resolution Nº 1603 (2004) of the Ministry of Education, Science and Technology, as well as the Bioengineer Professional Profile established in the in the 2008 Curriculum, the Informative Bulletins issued by our School's Extension Department and the document published by the Federal Council of Engineering Deans made public as the "Valparaíso Agreement" about Generic Graduation Competencies for an Argentinian Engineer.

From the Professional Profile, two central activities of a bioengineer's job can be identified: solving problems in the health-care area and designing equipment or systems to be applied in medicine using Basic Science and Technology skills.

At this point, Mathematics provides a language in which other disciplines such as Physics and technologies express themselves, and is present in scientific papers in the field. It also provides a logical framework for the Mathematical Models that often arise in the first stages of a design process and in problem solving. The use of appropriate software to do calculations and make both symbolic and graphical representations is part of a bioengineer's job, so we consider it important to benefit from its advantages to teach and learn Mathematics.

From these considerations the following goals are set for the third- and fourth-semester Mathematics courses:

- Applying the language, theoretical principles, concepts and fundamental methods of Vector Calculus and Differential Equations to problem resolution.
- Applying Vector Calculus and Differential Equations to devise Mathematical Models for biological, physical or other Bioengineering-related phenomena, with a degree of difficulty appropriate to the third and fourth semesters of the course, so that the student can understand their scope and constraints and interpret the results obtained in the context considered.Using mathematical software for problem resolution.
- Increasing the students' confidence in their own reasoning and strengthening their abilities for reflection and critical analysis.

At the UNER Engineering School, an electronic bulletin is weekly published which includes a section titled "Opportunities for Students, Graduates and Teachers." In order to gather information about the abilities and attitudes that the job market demands from Bioengineering graduates, offers published by the bulletin were analyzed from April 2014 to April 2015. We broke down requirements into two categories; the first one included the skills required to work in specific areas while the second comprised other personal abilities mentioned in the bulletins as "personal competencies," "personal characteristics," "soft skills," "transversal skills." A frequency analysis was performed on this category which is shown in Figure 3. This study in part supported the inclusion of the following goals:

- Reinforcing oral and written communication strategies.
- Working effectively in teams.

On the other hand, the cited CONFEDI document indicates that the fast pace of technological change and scientific advance in Bioengineering-related fields demands undergraduate students to develop skills and abilities to learn continuously and autonomously, assess their own learning, find the resources to improve it as needed, do a literature search on different media, select the relevant material and carry out a comprehensive and critical reading thereof.

Planning formative instances

Once the goals have been clarified, formative assessment instances are planned within the conceptual framework considered. Such instances are understood as "observation windows" through which information about the learning process is collected, which will help develop the improvements needed to meet the course goals. The following formative spaces are thus introduced:

Formative assessment in the context of the practical class: In the traditional design of practical classes the teacher does an introductory review of theoretical concepts, then solves a few examples on the blackboard and proposes other exercises or problems for the students to work on. This scheme has been replaced by a new one in which the student takes center stage. The class consists of a debate with student presentations on the blackboard. The discussion is centered on a piece of written output we have come to call the *Weekly Report*, which is prepared beforehand by the students working in small teams. The report consists of completing three or four exercises, but it has certain features that distinguish it from a regular assignment: In the first place it is not assessed with a grade, errors are not punished, and it is not required that it be presented fully completed and with the correct result. The wording of the problems encourages an analysis of the data provided, and the students are oriented through questions so that they will go through the different stages of each problem resolution, justifying each step with theoretical concepts or properties. During the resolution process, the students become aware of their own difficulties, which must be incorporated into the report to be shared during the discussion in the practical class. The written report is individual and consists of solutions or solution attempts, as well as the doubts and queries that have arisen, which are shared in the classroom debate. The group doing a presentation receives feedback from their classmates (*peer assessment*) and also from the teacher, who strives to create an appropriate environment for errors and misunderstandings to be expressed without fear. Furthermore, students perform *self assessment* by confronting their own developments and results with the debate conclusions, taking note in their worksheets of errors, correct answers and clarifications. At the end of the class, the teacher collects the reports to do a general review, prepare a list of difficulties, make suggestions and mark aspects not observed during self-assessment. Then the report is handed back to the students with the written feedback. When the assignment returns to the student it has undergone three instances of formative assessment.

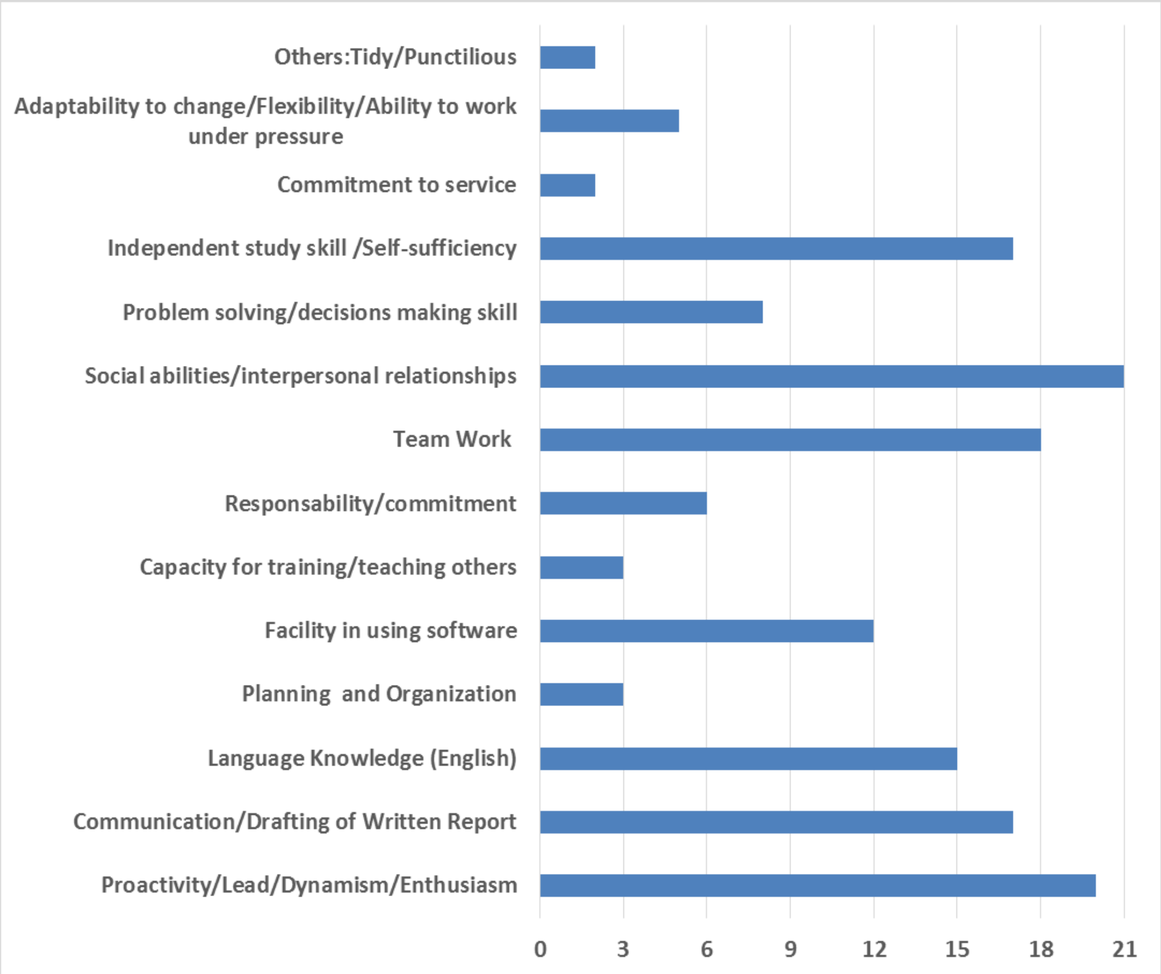

Figure 3: Frequency analysis of Transversal Skills required by the job market through the Informative Bulletins of the UNER Engineering School from April 2014 through April 2015.

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Formative assessment and computer lab assignments: The second homework assignment consists of the Computer Lab Assignments, in which problems are proposed that require the selection of a mathematical model and computer simulation thereof. These techniques are usually applied by bioengineers in the different stages of a design process, be it of an algorithm or a device. Computer simulation allows parameters to be changed and behaviors to be observed in order to make decisions conducive to an optimal design. The learning of these techniques is fostered in the Lab assignments through problems of appropriate complexity.

Initially, they were handed in at a scheduled date after a few instances of office-hour consultations. Currently, they are submitted through the virtual campus and draft submissions are allowed. Thus, the teacher observes the process and intervenes, not for correcting or grading at this stage, but to suggest revisions, improvements and deeper analyses. The virtual campus favors formative assessment, as it adapts to the student's schedule and allows digital drafts to be uploaded which contain graphs and code the teacher can provide feedback on as needed, thus fostering the student's reflection on what they did so as to improve on it.

5. Actions implemented

The Formative Assessment instances planned were implemented in coordination with the Summative Assessment activities. The latter include two Midterm Tests and the submission of the final version of the Computer Lab Assignments. Figure 4 shows the distribution of these activities along the fourteen weeks allocated to each course.

Week	Formative Assessment Tasks	Evidence about the Learning Process	Summative Assessment Tasks	Formative Assessment and Computer Lab Assignments
1	• Drafting of the weekly written report • Class discussion • Self-assessment			Computer Lab Assignment Nº 1 Team work with draft submissions through the virtual campus and teacher's feedback (Platform Moodle)
2		Information for planning the Revisión Week		
3				
4				
5				
6			**Computer Lab Assignment Nº 1**	
7	**Revision Week**		**Midterm Test Nº 1**	**Analysis of frequent errors and return.**
8	• Drafting of the weekly written report • Class discussion • Self-assessment	Information for planning the Revision Week		Computer Lab Assignment Nº 2 Team work with draft submissions through the virtual campus and teacher's feedback (Platform Moodle)
9				
10				
11				
12			**Computer Lab Assignment Nº 2**	
13	**Revision Week**		**Midterm Test Nº 2**	**Analysis of frequent errors and return.**
14	**Revision Week**			**Make-up Test**

Figure 4: Illustrates the articulation between Formative Assessment and the activities of the original Assessment Plan which only included Summative Assessment.

After the midterm tests, the teaching team works on the errors observed; an Error Categorization and an analysis of the most frequent ones have been prepared. We have worked with the following categories: Errors associated to the analysis of the problem wording, Reasoning errors (in the logical sequence of the solution procedure), Conceptual and/or methodological errors related to topics from the course, Errors associated to lack of verification, Errors associated to mathematical language and its link to other sciences, Basic calculation errors. Activities in the review week are centered on this information, which is useful for those students who need to take a makeup test, and also for teachers as it shows the difficulties that persist. Thus, the planned activities have incorporated teacher feedback, student self-assessment and work with peers into a fabric structured by the contents, the learning goals stemming from the bioengineer's professional responsibilities and the time available (14 weeks).

6. Results

The original assessment plan included Summative Assessment only and students were promoted if they obtained a minimum 80 points out of 100 in Midterm Tests and Laboratory Assignments. By inserting the formative dimension we incorporated a third requirement: Attending and participating in 80% of the Debates and submitting 80% of the Weekly Reports. At the end of the course, the student attains one of the following statuses: Regular, Promoted or External. This approach had a positive impact on the dynamics of the classes, and also on academic performance. The average of students who attained the Regular status jumped from a historical 56% to 62% in the Vector Calculus course taught in the first semester of 2014 and 74% in the course of 2015, while in the Differential Equations course taught in the second semester of 2014, the percentage of students who achieved the Regular status was 87%. Qualitative changes were also observed in student participation when: completing an assignment (written reports) not rewarded with a grade, explaining the resolution procedure for an exercise (rather than just trying to get to the answer), working with academic honesty in written reports and drafts sharing errors with teachers and classmates.

7. Conclusions

The Action-Research process described has brought about a change in our way of understanding assessment. It has not been easy to modify traditions that permeate assessment in engineering programs; overcoming such resistances has been possible only through long-term collaborative work. The project has included spaces to reflect on learning accomplishments, the teaching practices that made them possible, and the assessment tools used, and those reflections have provided both feedback and proposals for improvement. Much remains to be done, however; the teaching team is currently reshaping midterm tests and final exams, developing new assessment instruments, and seeking ways to improve the level of student participation in assessment, which will expectedly contribute to training critical Bioengineers, able to test their own knowledge and undertake further training along their life.

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