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Motivating and metacognition for engineering students

Abstract

This article presents an experience on motivation and metacognition in civil engineering students who participate in the subjects 'Elements of Environmental Engineering' and 'Workshop d Module on Environmental Engineering Extension' (ModEx). 'Elements of Environmental Engineering' is a course for all Civil Engineering students of all professional profiles. Initially, the elaboration of a guided monograph on some topic of the national reality proposed by the students themselves was required for passing. The monograph and the oral final were performed in groups. However, the growth in university enrollment meant that the ability to guide the monographs was exceeded and the subject began to be exonerated based on the result of two partial written exams. The Faculty decided to support the continuation of the monographic and that allowed a new optional subject to emerge: ModEx. ModEx addresses real problems that challenge both students and teachers. To guarantee a comprehensive training process, the student must have direct contact with social reality, which is an opportunity to ask questions that are not defined a priori in the traditional teaching process. In these subjects, giving students the role of protagonists in the development of the subject, proposing them to face real situations, working together with teachers and other classmates, are mandatory. The parenthesis of the pandemic implied the need to make an additional effort in both subjects to adapt to virtuality, without losing the special value of addressing issues that are not comprehensively addressed in current undergraduate studies and experiential contact with reality. But the challenge continues: the return to face-to-face courses finds us with courses specially redesigned with pre-pandemic students in mind, but current students are different. They show little interest in conventional face-to-face activities, but they are very interested on practical work, such as ModEx. In the design of new proposals for today's students, the holistic approach to problems nor the rigorous environmental engineering sight should not be lost.

Keywords: motivation, cognition, metacognition, University extension, engineering training, teaching for understanding, Uruguay

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Abbreviations: UdelaR, Universidad de la República; FING, Faculty of Engineering; UEFI, education unit of the Faculty of Engineering; TU, teaching for understanding; ZDP, proximal development zone; EEE, Elements of Environmental Engineering; ModEx, Workshop Module on Environmental Engineering Extension

Introduction

The more you study, the more you know.

The more you know, the more you forget.

The more you forget, the less you know.

So, why study?

(Chalk graffiti on a classroom wall at the Faculty of Engineering, UdelaR, late 1980s).

Universidad de la República (UdelaR) is the oldest University in Uruguay. It is over 130 years old. It is public and no tuition, which means that students are free of any monetary commitments: it is totally for free. Since the enrolment test was eliminated in 1984, the number of students at UdelaR has exponentially grown, and the Faculty of Engineering is no exception.

Since 1997, all Civil Engineering students at the Faculty of Engineering (FING) of UdelaR must complete a minimum of 7 credits in Environmental Sciences (1 credit = 15 hours of work). A dedicated course on Environmental Sciences was proposed ('Elements of Environmental Engineering', EEE).[1] For most of the students, it is the only one environmental subject throughout their undergraduate education. In the curriculum to become a Civil Engineering, practical subjects for bringing environmental issues closer to students, are recommended.

This paper presents a successful experience on motivation and metacognition of Civil Engineering students, related to their environmental education. It has been developed along many years. The first steps were related to the abovementioned subject 'Elements of Environmental Engineering'. Some years later, a new optional subject was proposed, and it is still active: the 'Workshop Module on Environmental Engineering Extension' (ModEx).

Students highly appreciate the way of learning and the different abilities they can improve at that course.

According to Dehaene,[2] there are four pillars on which learning is based: attention, active curiosity, error correction and memory consolidation. To capture the attention of our brain, it is necessary to focus on some stimuli and ignore others. Therefore, motivation is the key for achieving that selection, and for 'needing' to go deeper on the topic. The feedback to review and correct errors is external at first, but we need to develop the skills for being our own reviewers and reorder the new knowledge on the neural nets we have been developing since we were born; finally, we need to 'clean' the material and fix the new ideas in ways that make sense, in order to achieve a meaningful learning experience when memory is consolidated.

Flexible thinking is the essence of mindfulness; flexibility is an essential feature of intelligent thinking.[3–5] From the Mindfulness Learning school, Langer[4] states that mindfulness is "the simple act

of actively noticing things". For Langer, "if you learn something mindfully, you don't need to worry about remembering it, the information and knowledge will be there when you need them." Thus, if the work methodology, self-critical and metacognitive reflection are acquired in a "fully-conscious" or mindfulness way, it will be achieved -or at least it will have been attempted- to provide students with an effective tool that they can apply in other instances of work or learning.

The ability of review and correct our own mistakes can be learned and improved through metacognitive strategies. Metacognitive knowledge constitutes the declarative component of metacognition and includes knowledge of one's own cognitive resources, knowledge of the demands of the task and of the strategies that can be used. De la Torre[5] states that working on errors analysis is a powerful tool not only from a disciplinary point of view but also from a didactic point of view. He proposes delving into errors as an interesting teaching–learning strategy; sometimes the errors are common mistakes, but in other cases, they reflect preconceived ideas or misconceptions that need to be deconstructed and reconstructed in the right way. Metacognitive control constitutes the procedural component and includes planning processes of the appropriate strategies to solve a task, supervision and regulation of their use and their effectiveness, as well as progress towards the established goal and the evaluation of the results obtained.[6]

Teachers can collaborate with the development of the student's criteria through the feedback they provide: they must be clear about the errors but they must also give sufficient arguments about the strengths of the work, the weaknesses to be overcome and guidance on how to achieve the goal of improvement. The feedback, then, will become 'feedforward' and it will be useful to improve metacognitive skills.[7]

Material and methods

This case study is based on the experience about teaching Environmental Sciences for Engineering students, with focus on the subject 'Elements of Environmental Engineering'.[8,9]

Subject: 'Elements of environmental engineering' (EEE)

Monographs

In the beginning, the final evaluation of this subject was the oral argument of a monographic work developed in groups throughout the semester. The maximum number of students per group was limited to five. Both writing and argument finals were performed in workgroups. To carry out the work, each group had monthly meetings with their teacher outside class hours, in addition to permanent consulting at the end of classes. The monograph work contributed to give personalized attention that allowed the teacher to adapt more precisely to the difficulties, interests and concerns raised by the students, while trying to improve their learning strategies, expression and spelling difficulties (the quality of writing is a common weakness in engineering students). Since number of students was usually from 80 to 100, about 20 groups were performing their work simultaneously.

The topic of the monograph was proposed by the students. From the didactic point of view, the proposal of the monograph topic by the students has some interesting points. Among them, it should be noted that, if the students could realize that they had total freedom to choose the topic to study from an open list -which was the intersection of reality and their own interests-, and at the same time they could realize that they would have fluid and permanent assistance during the course, they looked for something "interesting" instead of looking for something "easy".[9]

The main difficulties detected during the first three years of lectures were the differences in the pace of work of the workgroups during the term, the lack of criticism of the students towards their own work in terms of their degree of progress, the sources of consulted information (quality, recentness, reliability, quantity), and their own production (quality, originality, syntax and spelling).[10]

Despite the good quality of their final documents, most students showed little interest even in the topic they themselves had chosen; they also did not attend the classes which were related to other topics of the course. That was not the aim of the subject, where all the important environmental issues for future Engineers were included. Furthermore, it was not easy to sustain the groups pace of work, avoid relationship problems within the groups and develop a critical point of view about the product they were obtaining -their monograph-. Thus, 'something' was not working well in the course and needed to be improved.

Changing the evaluation mode

To improve the evaluation mode, two written partial tests were added (the partial tests that most of the initial courses have). These tests were qualified only Passing/Failing; to get the Passing quality, the student had to get 40 % of each written test. Otherwise, they would fail. Also, to improve the groups' work, the promotion of a metacognitive approach in the learning process was launched with the Educational Unit of FING (UEFI). The UEFI gave firm and direct support to professors on the subject. The general aim was to encourage a greater systematization in the students' methodology of work, from a proactive critical point of view. The students had to complete a short form with some questions to answer individually and others to answer in groups. These forms had to be completed two weeks before the group monthly meetings. It was intended that students would reflect on their manner of working and easily visualize their strengths and weaknesses. Working this way, the students themselves could build their own tools and criteria to analyze their work in terms of methodology, pace of progress and results .[10]

Working on the self-regulation of the students' learning processes was highly appreciated by most of them. Students rarely receive direct instruction in metacognitive skills. The knowledge they have of their own cognitive processes and their metacognitive strategies, are merely naïve. Those who receive explicit instruction in this regard, regulate their own learning better than those who receive less instruction of this type. Domain-specific problem solvers not only have better organized and integrated domain-specific knowledge than novices, but also tend to act in a more self-regulated way when confronted with new kinds of problems or complex problems within their domain of expertise, for which they do not have a standard procedure to apply directly and automatically. Given the close relationship between the cognitive, the metacognitive and motivation, the effective instruction of learning strategies must be metacognitively oriented, seeking that students become more aware and more autonomous in their learning, but without forgetting that this metacognitive instruction must have the appropriate motivational and contextual supports.[10]

Despite being a more difficult path than the one originally proposed for the evaluation of the course, there was an improvement in the achievement of the objectives of the subject. Teachers also improved their teaching skills, studying and learning about approaches and tools from different schools, such as Langer's Mindfulness Learning

(2000), Teaching for Understanding (TU) from 'Project Zero' carried out by Harvard University (1999), the Proximal Development Zone ZDP of Vigotsky,[11] Project-based learning, among others.

From the perspective of Teaching for Understanding (TU), the aim is to achieve a level of understanding that allows the development of flexible performances of a certain complexity –without trying to reach the level of skills that TU designates as a Master's level. The key to maximize the potential of the monographs work lies in the fact that the proposal of the topic to be developed came from each group of students. It is intended that the topic of the monograph would be a true 'generating topic' (according to TU).[9]

According to Stone Wiske,[12] the generating topic must be mobilizing or, at least, interesting and accessible for the students; it should have relational potential -i.e., it should allow to search / find / develop connections with other sources or previous knowledge. When such a topic is proposed by the group of students, however, the responsibility of the teacher is to help them to visualize it within the conceptual framework of the subject, to guide them to find connections that should be useful to achieve an approach to the problem that allows the group to generate its own outcome.[10] According to the case study, the outcome should be a systematic analysis, a critical abstract, a numerical application, a simple design proposal, etc., clearly distinguishable from the background information they have studied.

In addition, there is a generalized idea that for "something" to be worth studying, it must be a problem. It is very difficult to visualize that they are only being asked for a topic and not for a problem, since rarely students have realized that for operating without generating environmental issues means that there is an environmental management that deals with "changing everything to let everything stay the same", as stated by Lampedusa. Thus, the idea that the Engineer is not a "problemologist" but a "solutionologist", working to improve the nowadays life of the society, should be strengthened.[8]

In turn, from the student perspective, the subject imposed by the teacher seems to have an implicit degree of difficulty, a tricky approach, or a not clear demand. When the students propose the topic to work, they feel freer. They must achieve their own outcome, but the difficulty does not "exist" in itself: they will define it, address and overcome it by working on a topic they choose. The students bring the topic to study, often with a naive level of knowledge (according to TU nomenclature), but then they formulate the questions to work on and build a way to search for the answers. This modality of work leads the students to prepare the proposal of the exercise they want to solve, which makes it "a problem" or a "case study", rather than an exercise. After this achievement, they have only one more exercise to solve.[10]

This approach in ModEx is much closer to daily professional practice than to the student perspective: in professional practice, posing the right questions usually provides almost half of the answer. Learning to pose the right questions about any case study is an important task for Engineering students. Taking advantage of previous experiences, concerns, curiosities, interests of the students around the topic they propose (mostly raised from a level of naive knowledge) to build on it a more rigorous approach, connecting to a central idea: the Engineer's laboratory is the real life, and changing it for the better is 'a must' of his work.[8]

Vigotsky's theory about amplifying the so-called "Proximal Development Zone" (ZDP) seemed to be a good way to work on for developing the monographs. Vigotsky's theory is based on the idea that a lot of things that are not possible to be done, learned, developed or understood alone, become possible when they are tried to in a team with the assistance of "an expert" to sustain the learning process. The expert can be the teacher, but Vigotsky promotes the high value of working with peers. He states that the ZDP is "the difference between a child's 'actual developmental level as determined by independent problem solving' and the child's 'potential development as determined through problem solving under adult guidance or in collaboration with more capable peers'".[11]

Finally, the growth of the number of students overloaded the possibility to attend the monographic works and the subject turned to be exempted based on the result of two partial written tests. In this evaluation mode, the "reset" of information after the tests makes most of the concepts remain as a diffuse memory of something that the students once heard.

The 'Workshop Module on Environmental Engineering Extension' (ModEx)

On the second part of the course 2004, the Faculty of Engineering decided to financially support the continuity of the monographs. Since the semester had already begun, it was decided to offer a mid-semester elective course, which was renamed the "Workshop Module on Environmental Engineering Extension". Working with a small group of highly motivated students, the experience was extremely successful. After that year, this workshop was accepted as an optional subject for the students; the teachers decided to connect it with another challenge: the University Extension.

University extension on environmental engineering

The University Extension is one of the three purposes of the University, as established in Article 2 of its Organic Law:[13] "The University will oversee higher public education in all levels of culture, artistic education, qualification for the exercise of scientific professions and the exercise of other functions that the law entrusts to it.

It is also incumbent upon it, through all its organs, in their respective competencies, to increase, spread and defend culture; promote and protect scientific research and artistic activities and contribute to the study of problems of general interest and promote their public understanding; defend moral values and the principles of justice, freedom, social welfare, the rights of the human person and the democratic-republican form of government".

It is a broad concept, which can include activities of a very diverse nature. Contributing to explaining the type of activities referred to, the Resolution of the Central Board of Directors of the University[14] establishes, in number 17: "As part of its commitment to society, the University promotes the curricularization of extension and the promotion of activities related to this university function, in close connection with teaching and research, based on a broad and plural conception that understands to university extension as the set of collaborative activities of university actors with other actors that, in interactive processes where each actor contributes their knowledge and everyone learns, contribute to the cultural creation and socially valuable use of knowledge, with priority to the sectors more postponed".

The University Extension in Environmental Engineering is a safe and direct way to accompany the students in a professional practice exercise. It is a way to put into practice the technical skills they have acquired in their training, to better understand some of the society problems and, when possible, cooperate to solve them. It is a way of internalizing the idea that the engineer must offer the best of his discipline and of himself, to actively participate in a society with which he has an ethical commitment as a citizen and as a professional.

A different way of learning

One of the first innovative tasks in the new subject ModEx lies in the 'decodification' of the main problem, to formulate it as the exercise to be solved during the course; then, learning how to present it with the structure of a project and preparing a detailed schedule are next tasks. The selection of an approach methodology, the study of regional precedent experience about the topic, the performance of practical tasks and preparing an oral argument of the final report are part of issues that, although they should be daily at this stage of the course, are positively valued both by the students as by the teachers of this Workshop.

The success of each of the subjects in having achieved the objectives pursued is gratifying. But it is much more so if you consider the enrichment that the working methodology brings to the protagonists, having reality itself as a "laboratory" and those who carry out the day-to-day of the problem to solve as teammates. This is also particularly valuable if it is considered that the first years of training in engineering tend to distance young people from their daily socio-cultural context, perhaps due to the demands on the theory subjects they must attend.[15]

Joining an interdisciplinary team, the holistic approach to problems, studying topics that are sometimes not exhaustively covered in the current under degree studies, coupled with intense field work and experiential contact with reality from all angles (human, geographic, economic, cultural) are typical characteristics of the exercise of environmental engineering in its most rigorous manifestations. In this way, better professionals are prepared, with greater commitment to the University, to their profession and to society and its growing demands. In the past, this way of working could usually be seen in the Faculty of Engineering as "anyone who wants to work on Environmental Extension issues can do it", and there were almost voluntarist expressions and experiences, without a real Environmental Engineering content. However, through these subjects it has been possible to show that the quality of the results obtained is not only related to the service vocation of those who are involved in it, but also to the disciplinary skills of the technical team and the work methodology.[16] It is possible to truly put environmental engineering at the service of society and generate in the future engineers a growing level of commitment towards the University, towards their profession and, above all, towards society and its demands.[17]

University extension during pandemic time

The University Extension model in Uruguay is based on collective meeting and movement, i.e., basically everything that could not or should not be done to comply with the social distancing measures imposed by the health authorities due to the pandemic of COVID 19. Then, the Extension, which by itself should be the most prepared university function to face an emergency, encountered serious operational difficulties. The crisis also shocked the day to day of the University Extension, which had to find a way to achieve a rapid rearticulation and keep up with the events.[16] From this first glance, the problem appears mainly as a methodological difficulty.

"How to do extension from social distancing? What type of territorial work is viable when it is not possible to mobilize teachers and students? With what tools to generate dialogue of knowledge, organizational processes and participatory approaches, if we are a screen away from our interlocutors"?[18]

The transition from classes to virtual mode was organized as quickly as possible, in such a way that the link with the students was not lost. Discover and define a clear work framework, where more than adapting contents, methodologies and work dynamics, a totally new proposal was needed. The link between teachers and students was strengthened, trying to understand the specific situations of the students and jointly proposing a space for study and technical training, but also for reflection. During this process, it was understood that nothing remains the same in crises, much less a training proposal, but at no time was reality denied, nor was teacher desertion contemplated. 'In a scenario riddled with the impossible (you can't go out, you can't hold face-to-face meetings, you can't, you can't), the possible takes on another value'.[18]

From the beginning, achieving the continuity of student participation in University Extension actions was a main concern. It was important to find ways to link courses with research, as a university function that would allow knowledge creation to predominate over the restrictions imposed by the pandemic. Like any crisis, the pandemic has made it possible to generate opportunities for the comprehensiveness of Extension training for our students, promoting research and enriching teaching.[16]

Three successful Extension experiences were carried out during the restrictions due to the pandemic: a Circular Economy plan for some companies installed in the Technology and Industrial Park of Montevideo; a health care waste management program at the University Hospital; and the development of acoustic panels made with wastepaper from the Faculty of Engineering.

It is worth mentioning that also EEE has changed a lot during the pandemic: the two written partials were replaced by a set of individual and group tasks, and the face-to-face classes became virtual consultation.

What happens after the pandemic time?

In 2022, everything seemed to return to the 'old normal', and UdelaR courses returned to the classrooms. But many things have profoundly changed.

Actually, the students are quite different than those we were working with before the pandemic times. In the first place, they do not have a clear feeling of belonging to the University; secondly, they are not used to spending time at the University for study, solve exercises or debate national issues with their classmates, because they handle most of their classes, homework and tasks virtually; and at last, they don't feel committed to issues like the students' power to change small and big things.

On the other hand, since they are more used to working alone and at home, they only go to the University for things that they consider interesting enough, and hands-on working is one of them. In 2022, there were about twice as many students at ModEx than before the pandemic, and all of them were very interested in the Workshop and its various activities.

The number of students enrolled in EEE has not changed significantly. Individual and group tasks continue to be the way to pass the course, and virtual consultations are now face-to-face. But most of the students do not go to classes and do not like to communicate/ask/raise their doubts through Moodle; they prefer to write an email directly to the teachers to clarify their doubts. During the period 2020-2022 we have carried out a voluntary questionnaire to learn the opinion of the students who have experienced the two options: written partials and individual and group tasks.

Results

In relation with the EEE course, most of the students had a good assessment of the evaluation through guided monograph works, both

for the dynamics and for the approach to reality of the subject. The metacognition experiences included when working with the UEFI, allowed to improve teaching and promote an activity that was highly valued by young people; but on the other hand, it required a lot of time on the part of teachers, much more than could be imagined.[8,9]

The change of evaluation method to compulsory written partial exams was the only possibility when the enrollment of the career continued to increase. But in turn, it allowed to offer another subject, ModEx. Few students used to attend this subject, but they were highly motivated and committed. Both the disciplinary results and the metacognition and expression results have always been highly satisfactory.

The changes that were made for reformulating the courses during the pandemic time were effective to go on with the classes in a virtual form. Even if we got few responses to the questionnaire, all the students have answered that the new evaluation has been a good change for them. Some of their answers said were:

"This new modality brings down to earth the concepts of the course notes"

"I think that thanks to this modality I was able to immerse myself more in the subject without having to neglect others and that helped me a lot."

"I would opt for this new modality."

"Definitely, I would opt for this new modality."

Even though, the return to face-to-face courses has evidenced that we have restructured and thought the courses for pre-pandemic students, who are not currently the ones who are taking them.

Conclusion

Teaching is a permanent challenge. There is no simple didactic strategy to sustain the motivation of the attendees or enhance the achievement of the classes. Testing didactic proposals others than conventional masterclasses is an interesting way of promoting TU. Experiences based on Vigotsky's ZDP theory have managed to maintain interest and improve the learning process. Teachers are now facing a new challenge: we need to revise once again our didactic proposals to recover the motivation of post-pandemic university students and help them improve their metacognition skills again. The way we are doing it has proven to be ineffective for these new students.

Although it may seem contradictory, Environmental Engineering is a scientific-technological career that, despite its level of specificity, requires a comprehensive vision of reality and an approach with great humanistic content. Emerged from "classical" Sanitary Engineering, the environmental engineer is at the service of society and must solve its daily problems and manage its reality in the best possible way, with a view to improving the quality of life of all its members on a day-to- day basis.

The work in University Extension in Environmental Engineering is an enriching and proactive way of bringing the students closer to reality and accompanying them in an exercise of rigorous professional practice, adapting the requirements to their level of technical training. Applying disciplinary skills to respond to specific problems or to contribute to a better understanding of some of them, favors internalizing the idea that the engineer does not need to seek or create problems to justify his training and his existence because he is not a "problemologist" but a "solutionologist" who must have a strong ethical commitment to environmental issues, not only as a professional but, above all, as a citizen.

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Conflicts of interest

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