

Physics for non-physicists - two bio-degrees reforms in Spanish universities: Health Biology and Biology

L HERRERA-MELLE¹, F CUSSÓ², G LIFANTE², A del ROMERO³ and M SANCHO⁴

¹ Spanish National Center for Cardiovascular Research (CNIC), 28029 – Madrid (Spain)

² Universidad Autónoma de Madrid, 28049 – Madrid (Spain)

³ Universidad de Alcalá de Henares, 28801 – Madrid (Spain)

⁴ Universidad Complutense de Madrid, 28040 – Madrid (Spain)

Abstract. We present a review of two different innovative experiences of Physics education for Bio-Sciences in two Spanish Universities - the Health Biology degree of the Universidad de Alcalá de Henares (UAH) and the Biology degree of the Universidad Autónoma de Madrid (UAM). Both experiences took place simultaneously and coincident with the implementation of Bologna Plan. Although they were developed under different contextual constraints, set by the respective Faculties, they share a number of similar pedagogical strategies which are analyzed. In both cases the reforms allowed a substantial improvement in learning results compared to those obtained in the previous Physics courses in the respective degrees.

1. Introduction

The fundamental changes that are taking place in the life sciences through interaction with other disciplines and the urgent challenges at global scale (health, food, climate change...), have prompted calls to action to reform physics studies for life science degrees [1,2]. These proposals try to strengthen quantitative and modelling skills for the coming generations of biologists [3]. The question is of relevance as, in many of these Biology degrees, students take only one or at most two semesters of physics, and their knowledge and acquired competencies in the subject will determine their professional future.

On the other hand, the students' performance results in the physics courses for Spanish biologists are often unsatisfactory, both for students and professors. This question has been a frequent subject of discussion in the specialized literature. A significant number of articles have been published describing the design and implementation of educational initiatives aimed at achieving improved academic scores, while at the same time developing interdisciplinary knowledge and competencies in students.

In this paper, we present a critical appraisal of two innovative experiences in two Spanish universities - the Health Biology degree of the University of Alcalá de Henares (UAH) and the Biology degree of the Universidad Autónoma de Madrid (UAM)- which allowed a substantial improvement in the results compared to those obtained in the previous Physics courses in the respective degrees. Here, we summarize both reforms, focusing on their main innovations, achievements and limitations, and also including some interesting questions raised during the

Teaching/learning physics in bio-areas and related degrees workshop debate hold at GIREP-MPTL 2018 Conference. As a final remark, we wish to make it clear that the most appropriate program for each Introductory Physics course for Life Sciences (IPLS) will depend to a great extent on the educational and institutional context and therefore the results presented here should be adapted to the different conditions in other scenarios.

2. From Biology to Physics: critical review of a reform of the Physics course for the Health Biology degree at the UAH

2.1. Context and background

Before the Bologna Plan implementation, the Biology studies in the UAH (5 years, 300 credits) included two Physics courses with 60 teaching hours (6 credits) each, which were taught during the first academic year. The first one was dedicated to fundamental concepts of Physics and was optional. Its syllabus covered the traditional material (mechanics, thermodynamics, fluids, electricity and magnetism, optics and radiations), with scope and focus modulated according to its biological meaning. The Physics of Biological processes in the second semester was compulsory for all degree students and was aimed at illustrating the value of physics to understand biological structures and functions (i.e. Biomechanics of animal locomotion, Thermodynamics of living organisms, Laws of scale in Biology, Electrodiffusion and nerve conduction, Optics and vision, Biological effects of radiations). The teaching methodology was traditional: lectures to groups of about one hundred students, both those devoted to theory (40 hours) and to problem seminars (20 hours), detailed information on each topic and personalized tutorials with the teacher, at the request of the student. The evaluation consisted of an exam, at the end of the semester. The results of this compulsory course were very unsatisfactory: from 2001 to 2008 the dropout rate remained at an average level of 50%, and the pass rate of the students who finished the course did not exceed 60%.

The main reason for this failure seemed to be, as expressed by most of the professors and students through different surveys, the insufficient basic training of the students in physics and calculus from high school. This was mainly due to the fact that having taken a physics course at high school is not a prerequisite to enroll in a Spanish Life Sciences degree. Besides, many of these students considered Physics irrelevant to their needs and interests as biologists. This rejection to Physics and quantitative reasoning greatly hampered the learning/teaching process.

To address that problem, it was recognized by the Department of Physics the need of a reform of both the syllabus and the methodology. The redesigning process started in 2009, when the new Biology and Health Biology degrees in the UAH, adapted to the European Higher Education Area, were established. Both of these degrees consisted of 240 ECTS and 4 years of duration, and included an introductory physics course of 6 ECTS -48 teaching hours, half of which should be theoretical classes and the other half practical classes (laboratories and seminars)- in the second semester of the first academic year. One of the main objectives of this necessary reform was to remove the “mental barrier” against Physics, which was present in most of the students. The main challenge at that moment was how to achieve that goal, and how to lead the students to introduce Physics in their day-to-day work agenda. It was not an easy task if we take into account that Physics was considered difficult and unconnected to Biology by most of the students. For these reasons, an effort was made to select the most adequate topics for life sciences, while at the same time keeping the core concepts and fundamental theories of physics. To this end, the syllabus was discussed with physics and biology professors, analyzing the relevance of the topics and their difficulty for students.

An invaluable reference and source of inspiration came from the call to reforming the IPLS courses issued by USA institutions: the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), the Howard Hughes Medical Institute (HHMI) and the Association of American Medical Colleges (AAMC) [1-3], in the framework of a general revision of the Life Science degrees. After an intensive debate promoted by the AAAS, the concerned academic

community agreed on the need to enhance the interdisciplinary reasoning and competencies in undergraduate students.

At UAH, the new design of the IPLS was initially applied to both biology degrees, although we only report here the design and results of the course taught in the Health Biology degree. As that degree only accepts a maximum of 100 new students each year and it was highly demanded, the access cut-off mark-was high (> 11 , out of 14). We summarize here the main challenges, characteristics and outcomes of this IPLS, over five academic years during the 2009-2015 period, as well as the main questions which were discussed in the final debate of the workshop, and also trying to answer them. A more detailed analysis of this reform can be found in reference [4].

2.2. Keys to reform

The traditional approach for IPLS courses for Biology and other bio-areas students was based on the standard physics syllabus with examples applied to the area of the bio-degree. Instead, a model based on a careful selection of subjects and a degree-specific strategy was proposed for the new course, with the aim of achieving a good conceptual physics understanding, and specially a positive attitude of students towards interdisciplinary thinking. According to that integrative view, the syllabus was based on a choice of important biological processes in which the underlying physics was clear and the needed mathematics simple, keeping a coherent structure of fundamental physics. The list of physics subjects and biology topics included:

- Thermodynamics of life (Order, complex systems and life. Metabolism and thermal regulation)
- Physics of fluids (Human cardiovascular system)
- Biomechanics (Principles of locomotion: terrestrial, aerial and aquatic. Human locomotion)
- Electromagnetism (Electrodiffusion and membrane potential. Action potential)
- Radiations (Typologies and interaction of radiations with matter. Biological effects of radiations)
- Optics (Optical and electromagnetic lenses. Physical basis of optical and electronic microscopes. The human eye: a clear example of the usefulness of the technologies for Biology).

The study of a subject started by introducing the biological process or function, then exploring the physics principles and context, and finally applying the physics responses to the biological problem. An example can be seen in the Appendix of reference [4].

This pedagogical strategy “from Biology to Physics” (top-to-down), probably the main innovation of the new design, proved to be very effective, firstly for motivating and secondly for disabling the mental barrier towards Physics experienced by most of the students. But this alone would not have been enough for an acceptable accomplishment of the learning goals. The experience of the previous Bachelor’s degree clearly indicated the necessity of students being engaged in a continuous daily work on the subject. And this proved to be the most difficult achievement.

Among all the instructional strategies used to try this, three of them proved to be crucial. The first one came from the faculty general organization, by dividing the general class into smaller groups of about 25 students for labs and seminars (50% of the lectures). This facilitated the personal communication between teacher and student. The other two strategies were innovations promoted by the instructor. One of them consisted of establishing a virtual space to continue the analysis of the questions posed in each seminar. This was always regularly controlled by the instructor, who provided support and stimulated the debate between the students, as well as evaluated their voluntary participation as part of the final mark of the course. Only about 10% of the students participated in those discussion forums, but the debates were followed by the majority of them, with about 20,000 entries to the website during the semester. The third innovation was to establish a continuous evaluation system of the theoretical part (75% of the subject). This offered the opportunity for students to know their progress and to identify their difficulties and give valuable information about the learning process to the professor. All these innovations implied additional commitment and work by the instructor, with the aim of helping students overcome the special difficulties of the subject.

Finally, a fourth important innovation consisted of adjusting the reform of the course (topic coverage, mathematics level, approaches and activities, assessment...) to the profile of the health degree, and also to the possibilities and needs of the students, who had a high cut-off mark. This was done on the basis of an annual assessment of the course results, in collaboration with some volunteer students, which implied modifications in the course content, mathematics level, pedagogical approach, activities in and outside the classroom, and also in the evaluation criteria [4].

2.3. Indicators and results

Important indicators of the course success were the improvements in the permanence of students until completing the course and gaining their qualification, as well as in the percentage of students who reach the minimum proficiency level required. Overall, during our five-course experience, the average dropout rate (those students who disconnected from the subject during the current course) was very low, only a 6%, as compared to that close to the 50% of the previous years, while the percentage of students who passed the subject was also significantly improved: 79% of students passing the subject over those who completed the continuous evaluation (although when we consider the number of passing students over those who started the continuous evaluation, the percentage decreases to 74%). These passing results improved compared to the previous situation, since there was about a 50% of failures. A summary of these outcomes is displayed in table 1.

Table 1. Average course outcomes during the period 2009-2015. See [4] for more details.

Completing course	Dropping out	Passsing evaluation	Failing
94%	6%	79% - 74%	21% - 26%

But perhaps the most objective indicator of the teaching-learning progress was the evolution of the results of the four partial exams done during the semester. While the first theory exam was only passed, on the 5 courses average, by 37% of the students, the percentage of success increased over the period, until the final 74%. This significant progress reveals that despite the deficient background of students on physics and maths, our strategy was reasonably efficient in developing competencies in quantitative reasoning and applying physics concepts to biology. The results are also consistent with a positive impact on the student attitudes towards the important role of physics in biology, which was observed through anonymous surveys.

The majority of students enrolled in the degree had not studied physics at high school. In this context one might wonder to what extent this fact conditioned the success of the course. The analysis of results shows a positive correlation between previous background in physics and final scores (figure 1). Moreover, there was a higher percentage of students without physics studies who needed re-assessment. The successive adjustments in the course design were effective in reducing the impact of the previous physics knowledge on the success, with the exception of the course 2012/13.

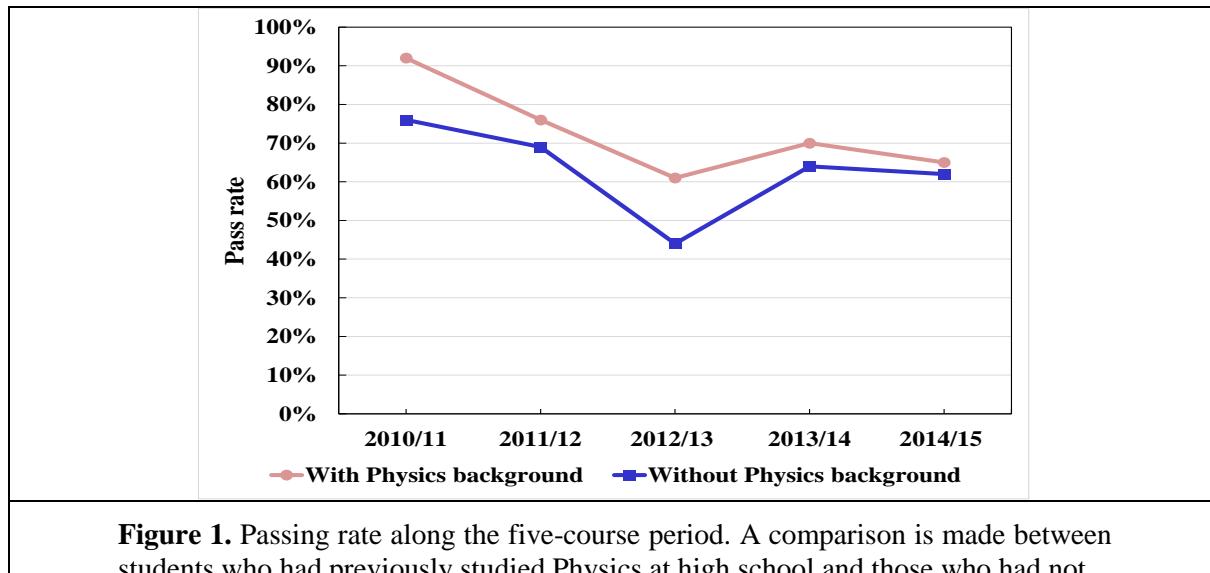


Figure 1. Passing rate along the five-course period. A comparison is made between students who had previously studied Physics at high school and those who had not.

2.4. Conclusions and implications.

The redesign of the introductory physics course for health biology students, based on a careful selection of topics relevant for biology, a top-to-down -biology to physics- pedagogical strategy and methodological changes oriented to individual assessment of students and feedback, proved to be successful in improving attitudinal and conceptual competencies of students. The results showed a substantial change in motivation and final scores compared to the previous situation. It has to be noted that we faced the challenge of covering the syllabus only in one semester. The Bio2010 report [1] proposes a list of physics concepts and skills needed by a future biologist and suggests three semesters to cover all this material. Alternatively, part of the syllabus could be integrated in other chemistry or biology courses. Our one-semester (6 credits ECTS) tried to cover the most pertinent part of these core concepts. Despite this important limitation, the results suggest that an IPLS developed under the guidelines described above can help the student appreciate the value of interdisciplinary thinking and develop to a certain extent physics reasoning applied to some biological problems. And this is also important to be understood by the students who had a very poor prior training in Physics and Mathematics.

Furthermore, the evolution in the assessment clearly demonstrates a positive progress as a result of a sustained effort by the majority of the students during their formative process. In addition, the top-to-down pedagogical strategy alone would most likely not have been enough, and nor do we know which would have been the results in a bio-degree with a lower access cut-off mark compared to that of the Health Biology degree.

Nevertheless, some additional issues remain to be addressed. The most important one is probably the content coverage, along with the depth of development of the subjects in the context of the actual possibilities of the enrolled students. In our experience, the adjustment of these two opposing elements was evolving towards a greater mathematical complexity of the physical models studied, coming closer to the real biological process. The list of topics could have been even more reduced for the sake of a higher level of in-depth understanding.

The 2011 report of the project *Vision and Change* [2] concludes with the following comments on the old “breadth versus depth” debate:

As biology faculty, we need to put the “depth versus breadth” debate behind us. It is true today, and will be even more so in the future, that faculty cannot pack everything known in the life sciences into one or two survey courses. The advances and breakthroughs in the understanding of living systems cannot be covered in a classroom or a textbook. They cannot even be covered in the curriculum of life sciences majors. A more tenable approach is to recast the focus of biology courses

and curricula on the conceptual framework on which the science itself is built and from which discoveries emerge. Such a focus is increasingly interdisciplinary, demands quantitative competency, and requires the instructor to use facts judiciously as a means of illustrating concepts rather than as items to be memorized in isolation.

Some studies relate a better performance of college students in the field of science to a reduction of coverage accompanied by an increase in depth [5]. Also, Pérez de Landazábal et al. [6], in the context of Spanish and Latin American students of Physics, suggest that, although the broad survey of the subject might seem intuitively appealing, it does not have advantages for most students. In our experience of the Health Biology degree, the technological applications of Physics (18% of the credits) could have been eliminated without compromising the principal learning objective, since its usefulness seems to be clearer for students.

The main subject of discussion in the final workshop debate was the pedagogical strategy question: which of the two alternative options - “from Physics to Biology”, or “from Biology to Physics” - is the most convenient for maximizing the development of physics competencies in biology students? This question has no simple answer and it depends to a great extent on the course environment. The “from Biology to Physics” approach, that is, physics taught in a biological context, implies reducing the syllabus extent but in return it improves the attitude of students towards physics and facilitates a significant learning of biological processes, integrating the contribution of physics into their understanding and strengthening the interdisciplinary vision of science. Furthermore, the problem of the contents is always present regardless of the strategy used, as long as the course only has 6 ECTS, a reality that occurs in most Spanish Biology degrees.

However, the top-to-down strategy presents some additional difficulties. One of them is the need of instructors with interest in the intersection of physics with biology, who catalyze the enthusiasm of students; this also needs the support from the department and faculty towards those instructors. Another difficulty that emerged in the workshop discussion is the lack of comprehensive supporting material for IPLS courses based on this orientation.

The access to adequate pedagogical resources for teaching in the intersection between physics and biology has been a recurring issue in the various forums and conferences on the undergraduate biology education held in the USA in the last decades. Thus, the 2015 IPLS Conference Report [7] called attention on the need of suitable resources:

...make it clear that the IPLS community needs to work together to create resources (lab manuals, lectures, topic sequences with a well-articulated rationale, homework, and exam problems) that can be shared and modified as required by local needs.

Several initiatives have responded to that need by creating or adapting distribution environments, such as repositories [8] or wiki websites [9]. See also the Appendix A of [7] for a comprehensive listing of available resources. But there is still need of new supporting material, especially of lab resources. In our case, the instructor searched through the available literature for relevant information that was provided to the students via the virtual platform of the course.

In any case, leaving aside the advantages and difficulties of both approaches, it seems clear that the degree of emphasis on one or another option for a successful implementation of the IPLS course must depend on the academic and institutional context. Institutions need to develop ways to promote interdisciplinary teaching and research at all levels. Physics and biology instructors should dialog about the content and methodology of the IPLS courses and ideally share experiences and teaching [10].

Any innovation implies a fear of change and a conservative resistance to modify views while losing the advantages of the traditional strategy. This explains why the traditional approach in introductory physics courses is still adopted by many instructors. But as the role of physics in biological principles and in biologist's practice increases, the need of an IPLS reform in the short term becomes more evident.

3. First year physics course for the degree of Biology at the UAM

3.1. Context and background

The context and background that we found for teaching Physics for Biology degrees at the Universidad Autónoma de Madrid are very similar to those described above in relation to the studies at Universidad de Alcalá de Henares, though we can find also some differences between both institutions.

The main similarity arises, obviously, because both centres share common regulations of National character. And, as mentioned before, Biology students arrive to the University through an itinerary where their curriculum includes only a preliminary compulsory course in Physics (Physics and Chemistry, to be precise). A second more specific Physics course is offered as an optative subject, but most Biology students refuse it in favour of the other topics (two optional subjects chosen from Biology, Technical Drawing, Physics, Geology or Chemistry).

As a consequence, most Biology students perceive Physics as a topic marginal to their needs, together with the fact that they have missed the adequate preparation in order to follow comfortably a Physics course of University level. The outcome is that many students develop a “mental barrier” against and become reluctant to the subject of Physics.

This is however in contrast with the feelings and perception of Biology professionals and instructors, who are increasingly aware of the relevance that Physics studies may have in the future development of Biology or other Bio-sciences graduates, in an increasingly multidisciplinary scenario. [2, 10 - 11].

All these thoughts were the conceptual background of the discussions which inspired the reforms that took place when the implementation of Bologna Plan in the academic year 2009-2010.

3.2. Keys to reform

In the case of the Universidad Autónoma de Madrid, and in contrast with most Science or Biology Faculties in Spain, the design of the new degree in Biology implied an increment in the time devoted to Physics. Before Bologna Plan, it was included as a one-semester subject in the curriculum of Biology studies (*Licenciatura*), with the equivalence of 6 ECTS while, in the new degree, it became a two-semester course with the equivalence of 9 ECTS.

The degree in Biology, emanated from the Bologna revision, implied a 240 ECTS degree, distributed in 4 years with 60 ECTS/year, with Physics allocated as a compulsory subject in the first academic year. Other subjects in the first year were Mathematics (6 ECTS), Chemistry (12 ECTS), Geology (9 ECTS), Zoology (12 ECTS) and Cellular Biology & Histology (12 ECTS). The 9 ECTS credits of Physics were allocated in a time schedule where during the first semester Physics was taught for 2 hours/week, while it increased to 3 hours/week during the second semester.

The teaching structure was such that around two thirds of the classes were dedicated to formal lectures while one third of the time was devoted to discussion of applications and exercises. Additionally, students attended three 4-hour laboratory sessions, to receive an introduction to experimental physics.

Let us detail now the structure of the new degree, in comparison with the previous “*Licenciatura*” studies:

As a first advantage clearly expected with the availability of a longer teaching period, the temporal planning of the course was allowed to relax. It was possible to address lectures with a preliminary slow pace, in order to let all the students follow the subject from the very beginning, overcoming the deficiencies inherited from previous training. It was possible (and necessary) to accelerate the pace at a later stage, particularly along the second semester, in order to cover all the syllabus contents.

In parallel to this approach, the implementation of a continuous evaluation system helped the students to self-evaluate themselves and the teacher to adjust the pace to facilitate the incorporation of nearly all students to the learning process. It must be said that this approach was proved to be very successful also for the students to gain self-confidence and to overcome mental barriers against the subject.

An additional pedagogical strategy was to adopt, if not a fully top-to-down structure (from Biology to Physics), the criteria of presenting a Biological issue as an objective to be reached and presenting the Physical contents as a way to better understand such topic. For instance, ultracentrifugation is presented as a Biological tool needed for future biologists, and rotational kinematics represents the physical background needed to properly understand it.

Within such orientation, the syllabus of the course was redesigned, stressing the Biology orientation both in contents as well as in the wording used to present the different topics. The list of physical principles and related biological topics included:

- Biomechanics 1: (Kinematics and dynamics, movement in a fluid, drag at low and high Reynolds numbers, centrifugation, origin of force in animals, muscles, principles of locomotion).
- Biomechanics 2: (Work and power, energy and its conservation, metabolism, biomaterials).
- Scaling laws and metabolism: (Scaling laws: isometry and allometry, scaling laws for energy, Kleiber's law).
- Fluids: (Ideal and real fluids, buoyancy, circulatory system, Bernouilli's equation and flight, surface tension).
- Thermal processes and principles of thermodynamics: (Temperature and heat, principles of thermodynamics, phase changes and thermo-regulation).
- Bioelectromagnetism: (Ionic diffusion and membrane potentials, Nernst equation, electrical mobility and electrolytes, action potential and nerve cells).
- Waves: (Acoustic and electromagnetic waves, light and sound & its perception, animal eyes, optical instruments: from the magnifying lens to the microscope).

Another important factor in the reform was to increase the time dedicated to exercises and their discussion. This, again, was one of the approaches emphasized by the Bologna Plan, which in the present case, was set up to be one third of the overall teaching time.

The pedagogical approach preserved the spirit already explained of adopting a low pace first to be gradually increased. The procedure followed was to deliver to the class, through the course web page, a set of exercises during the time used to present the corresponding contents of a given section, with the objective that those exercises would be presented and discussed by the students during the sessions allocated for that purpose. This strategy was based in order to promote active learning with its well accepted and demonstrated instructional benefits. [12].

A third element, also facilitated with the availability of a longer teaching period, was the possibility to briefly review some of the mathematical tools needed in the course (vector algebra, for instance), presented immediately to be needed and reinforced with the corresponding exercises too. Anyhow, the approach adopted was to always emphasize first the intuitive approach and physical background, addressing then the formal descriptions.

Finally, a fourth component of the reform, was the evaluation procedure. Three partial examinations were introduced as part of the continuous evaluation system (70 % of the final qualification), with the remaining components being the evaluation of laboratory reports (20 %) and the evaluation of the exercises discussed along the course (10 %). It must be said that, this last component, while minor in its percentage, represented a key motivation factor to the students, becoming a major driving force to impel/drive the students to an active participation in the course. Additionally to the continuous evaluation procedure, the possibility of a final examination was preserved in the new evaluation system; something which was only exceptionally needed.

3.3 Results and analysis

As a summary of the reform's outcome, Figures 2 and 3 present a comparison of performance data of the students along a fourteen years period, seven before and seven after the implantation of the reform in the Physics studies of the Biology degree at the Universidad Autónoma de Madrid.

Figure 2 represents drop-out data corresponding to the Physics course (percentage of students who began the classes but did not complete the evaluations). It can be seen that the figures fluctuated

around and average of 17 % while after the reform, the average drop-out rate was reduced to an average of 3 %. Figure 3 shows the percentage of students taking the examinations (drop-out numbers excluded) who reached the minimum rating to qualify. Here the figures fluctuated around and average of 75 % prior to the reform, increasing to a 94 % afterwards.

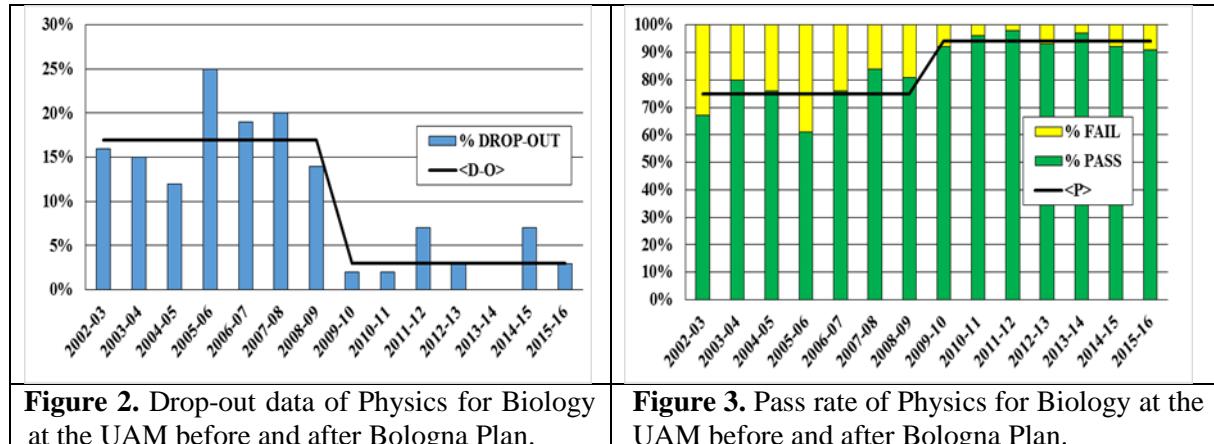


Figure 2. Drop-out data of Physics for Biology at the UAM before and after Bologna Plan.

Figure 3. Pass rate of Physics for Biology at the UAM before and after Bologna Plan.

These data are possibly the best indicators of the success of the reform, though they have to be analysed properly, considering the many factors that affect such results.

To understand the dramatic reduction in drop-out figures that accompanied the reform, it should be taken into account the changes in regulations that supplemented it. The policy regulating the permanence of students changed from a fairly relaxed legislation to another substantially more restrictive. This probably changed the attitude of the students, who previously could take the option of delaying the examinations of Physics to subsequent years, rather into the first academic year, and possibly was responsible of the high figures in drop-out before the Bologna Plan. Afterwards, the students were bound with more strict conditions, and therefore had to assume a higher degree of participation.

In relation to the figures of the number of students qualifying, though the evaluation process changed, we may say that the standard of the exercises and questions proposed in the examinations were basically of similar level, so that the increment in qualifications could be mostly attributed to the success of the reform.

From the elements introduced in the reform, we consider that the regulation of the pace, who allowed a progressive learning sequence, together with the reinforcement of the Biology-oriented syllabus, could be the main factors responsible for the success. This changes influenced very positively students' attitude and engagement, providing a much more active approach leading to an improved learning. [13 -14].

Let us consider also some final considerations: One is that, although a substantial number of the students accessing to the Biology degree at UAM were lacking of adequate background in Physics, they had a good global qualification (the cut-off marks to access the Faculty was > 10, out of 14). That means that the students had a general positive attitude for learning and also the commitment to make any effort necessary to reach the needed academic standards. So, they were very receptive to the initiatives of the reform, behaving very proactively.

A last point that deserves to be mentioned is the risk underlying when adopting a progressive teaching rhythm, which is the possibility that the most advanced students became discouraged. No doubt this is one of the main concerns that the instructor should keep in mind when following this strategy. The solution adopted in order to prevent that situation, was to complement the slow progress with pieces of advanced level (including papers from the scientific literature), explicitly offered to the students with the higher background level.

4. Final remarks

As a final remark, we consider that measuring a course's success is a complex task, especially if mastering the subject requires reasoning skills and understanding rather than mere memorization, as is the case of Physics. The main indicators, dropout and passing rates, have always a subjective component as they depend on the professor (level of difficulty of exams) and on the students (cut-off mark, previous training, etc.). Things which work for some students may not work for others, and what is achieved by a professor may not be achieved by another one having the same group of students.

Keeping this in mind, we could consider that the results of the reforms implemented both in UAH and UAM seem to indicate that they pointed towards correct directions.

These reforms were adopted independently, although they share a number of common elements such as a top-to-down (from Biology to Physics) orientation, including an effort to make a careful syllabus selection to emphasize biological contents; as well as initiatives to promote active learning via seminars, exercises and continuous evaluation. These components could be responsible of the success of these reforms.

Nevertheless, we are well aware that the results will depend to a great extent on the educational and institutional context. Obviously, we do not suggest that the reforms here presented provide a universal solution, but we think that represent an experience that could be adapted and tested in other environments.

In any case, we believe that many of the IPLS courses taught in Spanish universities (and probably European) should undertake a deep reform to better fit the needs of future life science specialists, which should be triggered from a dialog between biologists and physicists, as well as their respective Faculties and with the participation of scientific societies. We have called to open this debate from different forums [15]. Meanwhile, an invaluable source of inspiration can be found, in particular, in the US debate about the IPLS reform, driven by the "call to action" of *Vision and Change*. Its recommendations include enhancing the importance of basic sciences in the curriculum, a task that possibly should be undertaken at high school, in order to efficiently respond to the challenges that the interdisciplinary education is demanding nowadays.

Acknowledgements: One of us (FC) thanks a travel grant from Vicerrectorado de Coordinación Académica y Calidad (Universidad Autónoma de Madrid) under the initiative for Teaching Innovation.

LHM participated in the GIREP-MPTL 2018 on behalf of the project IPLS-Spain [16], promoted and supported by an inter-university group of physics teachers and young biologists [17].

5. References.

- [1] Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century 2003 *Bio2010: Transforming Undergraduate Education for Future Research Biologists* (The National Academies Press, Washington, DC)
- [2] American Association for the Advancement of Science 2011 *Vision and Change in Undergraduate Biology Education: A Call to Action* ed CA Brewer and D Smith (AAAS Press, Washington DC)
- [3] Redish EF et al. 2014 NEXUS/Physics: An interdisciplinary repurposing of physics for biologists *Am. J. Phys.* **82** 368-377
- [4] del Romero A, Sancho M and Ortiz P 2018 La Física en la formación de los biólogos. Balance crítico de una experiencia de cinco años en un grado en Biología *Lat. Am. J. Phys. Educ.* **12** 2309 1-10
- [5] Schwartz MS et al. 2009 Depth versus breadth: How content coverage in high school science courses relates to later success in college science coursework *Sci. Ed.* **93** 798-826

- [6] Pérez de Landazábal M C et al. 2010 Comprensión de conceptos básicos de la Física por alumnos que acceden a la universidad en España e Iberoamérica: limitaciones y propuestas de mejora *Lat. Am. J. Phys. Educ.* **4** 655-668
- [7] The American Association of Physics Teachers, *Conference on Introductory Physics for the Life Sciences Report*, AAPT, College Park, MD, 2015
- [8] NEXUS/Physics website, <<http://nexusphysics.umd.edu/>>
- [9] Conference on Physics in Undergraduate Quantitative Life Science Education, 2009, George Washington University, Washington DC, wiki website, <<http://ipls.wiki.daymuse.com>>
- [10] Meredith DC and Bolker JA 2012 Rounding off the cow: Challenges and successes in an interdisciplinary physics course for life science students *Am. J. Phys.* **80** 913-922
- [11] Stephanel A 2018 Promoting active learning in physics courses for the agro-food degrees *GIREP-MPTL 2018 Conference*, San Sebastian (Spain)
- [12] Zuza K, Garmendia M, Barragués JI and Guisasola J 2016 Exercises are problems too: implications for teaching problem-solving in introductory physics courses *Eur. J. Phys.* **37** 055703
- [13] Deslauriers L, Schelew E and Wieman C 2011 Improved learning in a large-enrollment physics class *Science* **332** 862-864
- [14] Guisasola J, Zuza K, Ametller J, and Gutierrez-Berraondo J 2017 Evaluating and redesigning teaching learning sequences at the introductory physics level *Phys. Rev. Phys. Educ. Res.* **13** 020139
- [15] del Romero A et al. 2017 La Física en la formación de los biólogos del siglo XXI. Reflexión y propuesta para los grados españoles en Biología *Revista Española de Física* **31** 24-28
- [16] Project IPLS-Spain website: <<https://www.researchgate.net/project/Introductory-Physics-Life-Sciences-for-BSc-Biology-in-Spain-IPLS-Spain>>
- [17] Biólogos sin barreras website: <<https://biosinb.wordpress.com/>>