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Learning nuclear chemistry and radiochemistry through a massive open online course

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Summary. — A MOOC on Nuclear and RadioChemistry (NRC) has been developed within the EU-H2020 MEET-CINCH project, in order to attract more students towards the discipline and increase people awareness. The course is divided into five "weeks" highlighting the importance of radiochemistry and nuclear chemistry for environment, health, industry, nuclear energy and society. Each week consists of different modules covering all possible applications of NRC within the week topic. The module follows a pedagogical framework designed *ad hoc*, that gradually introduces the topic to students, giving them different examples and applications to understand the theoretical concepts and to acquire a technical terminology. Feedback obtained by the pilot edition showed very good results: despite the short duration of the course, 25% of the 203 users successfully completed the course achieving the Certificate of Accomplishment. The answers collected in the inital survey and the final customer satisfaction questionnaire showed that users belonged to the selected target group and greatly appreciated the presence of practical examples and the different lesson formats adopted. The MOOC objective of attracting new students towards NRC appears to be on a good track, however this can only be confirmed by monitoring the next MOOC editions.

1. – Introduction

Nuclear and RadioChemistry (NRC) is essential for society, although it is not well known. There are many practical applications that rely on NRC and that people unconsciously exploit, since they have strong connections with everyday life. For example, the advantages given to industry or medicine have led to many improvements and to the introduction of new techniques that positively affected health, economy and environment. Unfortunately, nowadays the misperception of the public towards anything that is "nuclear" has caused a decrease in the number of qualified staff in this field.

To overcome the lack of experts with these competences, one of the possible actions is to increase the number of students of NRC [1, 2]. An educational approach based on a Massive Open Online Course (MOOC) could be useful to pursue this scope. Indeed, MOOCs have received increasing attention in recent years for their potential to engage students in active learning while conveying knowledge to a broad international public [3]. In this perspective, the MOOC could be a very effective way to increase students' awareness about NRC. Having open access, the course provides the ability to reach a massive number of students, worldwide.

The peculiarity of the MOOC course, adapted to a controversial and specialized discipline such as NRC, paves the way to a spread of knowledge that could be potentially addressed to different target groups, from the general public to students, such as pupils, high-school students, bachelor students or master students, by approaching the teaching more and more in depth. Furthermore, the MOOC structure can be opportunely adapted to different themes with different levels of detail. Nevertheless, to be effective, a MOOC has to be opportunely designed.

The present paper describes the development process of a MOOC devoted to NRC. The MOOC titled "Radiochemistry for Society" has been carried out within the H2020 MEET-CINCH project with the collaboration of 12 partners from 9 European countries including universities, research institutions and partners from industry. The MOOC lays its foundations on a specifically designed learning path, able to drive the users to discover the role of R&D activities in NRC for the modern society. The course aims at revealing the numerous applications that rely on NRC skills, other than the more obvious context of nuclear energy production, useful for a university choice as well as for a civic awareness. The results achieved in the first pilot edition are presented and discussed.

2. – The pedagogical framework

A careful analysis of target and context has led to designing a completely online path able to engage users aiming at the achievement of effective awareness and durable knowledge [4]. The target group has been identified in students that are already pursuing scientific studies: in chemistry first, but also physics, biology, nuclear medicine and engineering. Taking into consideration the prerequisites and the time needed to acquire a basic comprehension of such a difficult discipline, bachelor students have been selected. After target group identification and context analysis, the general didactical goals, expressing the broad aims an instructor has for a given course, and the learning objectives, describing the measurable things students will know and be able to do upon leaving the course, have been identified and the way to let students get learning objectives has been chosen. Such a methodological approach is described in the pedagogical framework, according to which the MOOC has been developed [4]. The pedagogical framework represents a structure specifically designed starting from the analysis of the context, the shared outcome and the identified target group. At the basis of each MOOC module, it is paramount to lead teachers to organizing contents in single lessons and assure high-quality teaching. The creation of a module requires the evaluation of the *learning goals* and *learning objectives* related to that topic, that are consequently divided into different lessons following the pedagogical framework. Therefore, each module gradually introduces the topic to the student, gives him/her different examples and applications to understand the theoretical concepts and principles of operation, and to acquire a technical terminology. Furthermore, the student can apply and verify the acquired knowledge by means of questions or exercises present in each module.

In particular, the first two lessons of each module are the *diving* step of the pedagogical framework: a simple every-day situation, which everyone can meet and that apparently has nothing to do with NRC, is described. Then, in the following lesson, the teacher gives the key to read the previous situation: the teacher goes over the moments connected to NRC, highlighting where and how radionuclides and radioactivity are involved. The lesson does not explain theoretical concepts or introduce technical lexicon, it has the only objective to make the user aware of the involvement of radiochemistry and nuclear chemistry behind that situation. This explanation is meant to be easy, it does not need a scientific background, so that it can be understood by a wider audience, such as the general public.

Then the actual educational session starts: the third lesson of the module is the introductory one, where an overview of the topic is given to the student and some basic concepts of NRC are introduced. The module topic is presented with a systematic explanation, introducing technical words and definitions. This step belongs to the content systematic organization step.

In the following lessons, the module topic is fully explained: the concepts are deepened with strengthening lessons. Several examples are introduced to highlight all the applications, enabling to show laboratory or industrial activities and equipment. Then, exercises and self-assessment quizzes allow the students to apply the acquired competences and skills as well as check their understanding. A useful link section, containing web links to freely available strengthening materials or relevant institutional websites, has been added to help users in further developing his/her NRC knowledge and awareness. The final assessment quiz contributes to the final evaluation and, by attributing a score, enables the users to get the Certificate of Accomplishment.

Different lesson formats have been chosen: video, article, infographic, quiz, exercise or links. Particular care was taken in the selection of the images/tables/schemes to be included in the lessons. Indeed, the graphics should help the student to understand better the topic and, since there is no direct interaction, they should not rise additional questions.

3. – The MOOC structure

The MOOC is divided into five *weeks*, each highlighting the importance of radiochemistry and nuclear chemistry for a specific area: environment, health, industry, nuclear energy and society. Each week comprises different *modules* covering all possible applications of radiochemistry and nuclear chemistry within the specific week area. The topics within radiochemistry and nuclear chemistry, relevant to give an overview of all the possible applications of such discipline, are gradually introduced along all the MOOC modules. The topics are analysed on the basis of the target group, always taking into consideration that the MOOC scope is to increase their interest in the subject and not to replace a university class. The MOOC structure is reported in fig. 1.

The first week on "radiochemistry for the environment" introduces natural radioactivity to students by defining several basic concepts, such as what a radionuclide and a radioactive decay are. Then, the students become aware of the production of artificial radionuclides by nuclear fission or particle accelerators, as well as the presence of abnormal concentrations of natural radionuclides, called TENORMs, as a consequence of anthropogenic activities. Students may understand the importance of environmental monitoring and remediation for making such activities safe for people and environment, as well as the radiochemical methods applied to this purpose.

1. **Radiochemistry for the environment**
   - 1.1 Natural radioactivity
   - 1.2 Radioactivity from anthropogenic activities
   - 1.3 Environmental remediation
2. **Radiochemistry for health**
   - 2.1 Nuclear medicine
   - 2.2 Sterilization by ionizing radiation
3. **Radiochemistry for industry**
   - 3.1 Tracer technology
   - 3.2 Radiation processing
4. **Radiochemistry for nuclear energy**
   - 4.1 Reprocessing of spent nuclear fuel
   - 4.2 Confinement and Waste management
   - 4.3 Decommissioning of nuclear facilities
5. **Radiochemistry for society**
   - 5.1 Cultural heritage
   - 5.2 Nuclear forensics and proliferation

Fig. 1. – The MOOC structure.

Week 2 describes radiochemistry at the service of human health. The user becomes aware of the production of radiopharmaceuticals, along with the use in nuclear medicine for both diagnosis and therapy. Another application of ionizing radiations and radionuclides is for sterilization purposes: in this module radiation chemistry is presented and introduced by discussing the effects of different kinds of ionizing radiations on contaminants (bacteria, fungi,...) present in food or on medical supplies.

The third week is dedicated to the less known but not less important industrial applications of NRC. The use of radiotracers for monitoring or investigating industrial processes is described, as well as the development of nucleonic gauges with sealed radioactive sources for reliable non-destructive measurements of relevant physico-chemical parameters even in adverse industrial environments. The overview in industrial applications is completed by introducing polymer radiation chemistry and by explaining how it has been exploited over the years to improve materials properties and produce innovative materials for high-tech applications.

The most obvious application of NRC in nuclear industry is discussed in week 4: by presenting the nuclear fuel cycle and the reprocessing of spent nuclear fuel to make nuclear energy more sustainable; by giving information about the safe confinement of radioactive materials and the management of such hazardous waste; and by explaining what nuclear decommissioning consists in, since nowadays it has strongly become a topical subject.

Finally, the MOOC is completed with some fascinating examples of the application of nuclear techniques in cultural heritage preservation and in nuclear forensics.

All the materials have been deeply revised during all the production process, in order to assure homogeneity and uniformity, as well as high scientific quality. All the materials have been uploaded on the POLIMI Open Knowledge (POK) platform and submitted to a debug phase by experts, to find and correct further errors within the online platform before the release of the course to the users. The so-developed course consists of 152

lessons, comprising 52 videos, 23 infographics, 34 exercises/quizzes and 33 articles, and the estimated effort to complete a week is about 5–6 hours.

4. – Pilot edition feedback

The first edition of the MOOC was a 3-month pilot edition available from the end of May to the end of August 2020 at the Polimi Open Knowledge (POK) website. The course has been launched and promoted by different institutional channels and social networks. This first edition was followed by 203 users from 20 different countries all around the world, the majority from Italy, Slovenia, Germany and Norway.

Among the 203 MOOC users, 52 (22 female and 30 male users) completed the MOOC and obtained the Certificate of Accomplishment: despite the short duration of the MOOC edition, 25% of users completing the course is a very good result with respect to the percentage usually observed for such kind of course. In addition, the average score achieved in the final exam is equal to 0.91/1.

At the beginning of the MOOC, users were asked to take an initial survey, aiming at collecting data about place of origin, age, gender, employment status, study subject and information source. The survey was not mandatory and only 37 people took it. Figures 2 and 3 collect the answers about the age of the users and the study subject.

Interestingly, the users are mainly 20–25 years old students in scientific areas, as the selected target group with good balance between females and males. Furthermore, web and social networks resulted not to be the most used promotion channels. Institutional websites or teachers were the most preferred way to get information. It is worth to note that among those who responded, women are the majority and that also some employed people chose to have a look at the MOOC.

At the end of the course, users were requested to answer a customer satisfaction questionnaire: only 27 answers were collected. The majority of such users stated that they joined the course for personal and professional interest (fig. 4), and studied almost all the learning resources working more than 4 hours per week. With respect to an estimated effort of about 5–6 hours/week, 44% of users think that the commitment in the MOOC was more than expected, while 52% found it to be as expected. Among all the aspects of the MOOC, the most favourite ones resulted to be the presence of several

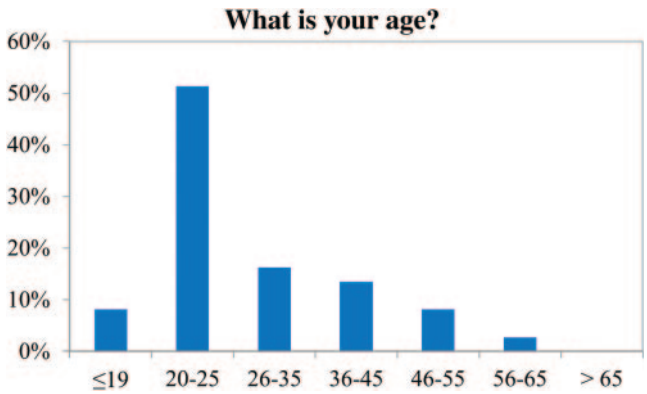

Fig. 2. – Responses to the question “What is your age?”.

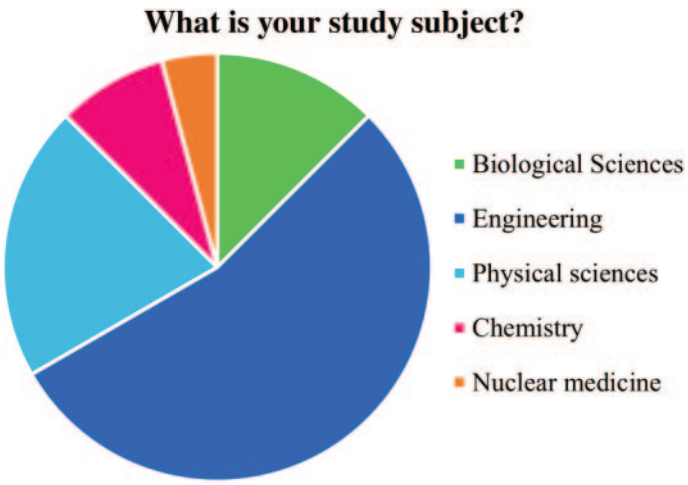

Fig. 3. – Responses to the question "What is your study subject?".

practical examples, followed by a good alternation of lessons and exercices. Overall, the course experience was positively rated (fig. 5).

Furthermore, users who answered the customer satisfaction questionnaire confirmed that they had acquired new skills or improved their existing knowldge on the topic, and therefore would recommend the course to colleagues.

In addition, during the pilot edition, users actively interacted with the teachers by sending several comments and questions on the *Discussion Forum* and also among themselves by exchanging comments on exercises. This feedback allowed to solve some technical problems but also to highlight the most interesting topics for users or the most difficult ones. In particular, first feedback about the effectiveness of learning could be deduced from the results achieved by users in the final exams of each module. The highest average score was observed in Week 1 "Radiochemistry for the environment" (0.93/1), while the lowest one was registered in Week 2 "Radiochemistry for health" (0.82/1). Overall, the evaluations were very high, but they highlighted some differences in the achievement of

Fig. 4. – Course joining motivations.

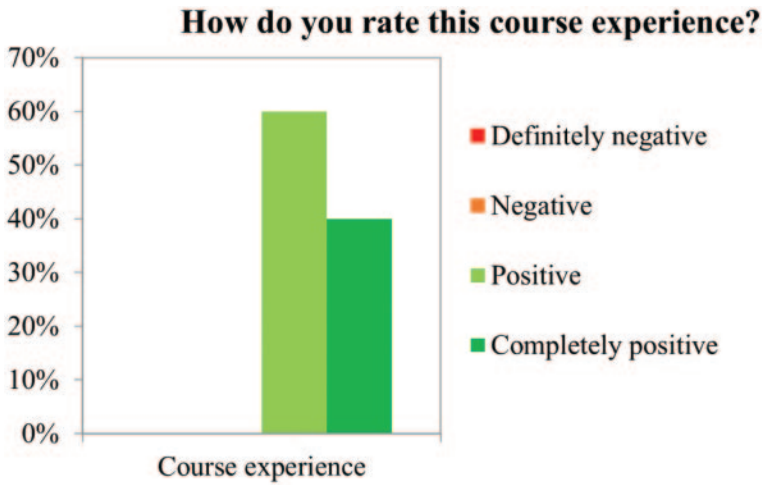

Fig. 5. – Course experience appreciation.

learning goals. Such results will be analyzed in correlation with some relevant features, such as the specific theme, the module structure, the lesson types in the module, the scientific level, and so on, and will be carefully considered for a continuous update of the future MOOC editions.

5. – Conclusions

Radiochemistry and nuclear chemistry contain key knowledge for the modern society, that needs to be maintained. The MOOC "Radiochemistry for the Society", designed for bachelor students in scientific areas, combined a powerful tool as MOOC and a specifically designed engaging approach to a complex and quite unknown discipline as NRC, with the objective to increase students' pull to this field. The feedback obtained by the first 3-month pilot edition of the MOOC showed a good participation of students and a good percentage of them were able to achieve the Certificate of Accomplishment. Such results could be attributable to the effectiveness of the adopted pedagogical framework in engaging the students, but also to a real interest in going deeper into such themes, interest that further has grown by discovering all the applications of NRC. The feedback obtained during the pilot edition will be fruitfully used to improve the next course editions from the point of view of clarity and completeness. The MOOC objective of attracting new students towards NRC appears to be on a good track, however this can only be confirmed by monitoring the next MOOC editions. The first MOOC full edition started at the end of August 2020 and will be available on POK (`https://www.pok.polimi.it/courses/course-v1:Polimi+ERS101+2020_M8/about`) for a year.

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