



A MOOC in Nuclear- and Radio-Chemistry: from the design to the feedback

Maddalena Negrin¹ · Elena Macerata¹ · Francesca Concia² · Mario Mariani¹ · Eros Mossini¹ · Sudeep Das³ · Anu J. Airaksinen³ · Marko Štrok⁴ · Vivien Pottgießer⁵ · Clemens Walther⁵ · Petr Distler⁶ · Jan John⁶ · Mojmir Nemeč⁶ · Teodora Retegan⁷

Received: 29 June 2022 / Accepted: 8 August 2022 / Published online: 11 October 2022
© The Author(s) 2022

Abstract

Recently, the loss of expertise in the nuclear- and radio-chemistry (NRC) is becoming an issue of concern, because of few engaging curricula and career prospects.

To counteract this trend, the Massive Open Online Course “Essential Radiochemistry for Society” has been developed with the intent of letting young students in scientific matters discover all the benefits of NRC to society and improving their awareness of these disciplines.

The MOOC development process as well as the feedbacks collected in the first MOOC editions are analyzed by highlighting strong points and weakness of the followed strategy.

Keywords Massive Open Online Course · MOOC · Nuclear chemistry · Radiochemistry · Open Education · Distance learning

Introduction

Expertise in nuclear and radiochemistry (NRC) is of strategic relevance in the nuclear energy sector and, in general,

in several vital applications for the modern society [1]. Indeed, the competences typical of NRC are not only fundamental for facing the challenging tasks of the safe nuclear power plant operation, their future decommissioning, or the nuclear waste management, but also paramount for assuring several NRC applications in non-energy fields. Progresses achieved in diagnostics and therapy within nuclear medicine is one of the most meaningful examples of how society could benefit from continuous enhancement in scientific knowledge within NRC. Similarly, other fields, such as radiation protection and radioecology, nuclear forensics and safeguards operations, as well as dating techniques for geology and archaeology, are all based on NRC knowledge. Despite its relevance, NRC is not widely taught in high schools and universities. It is perceived as not a modern field of chemistry and, even where available, it is not among the most selected subjects. However, the low number of students in NRC is a possible consequence of the small number of graduates in STEM (Science, Technology, Engineering and Mathematics) fields. This general issue is due to the low number of applications and the high number of dropouts, related to a scarce students' motivation or a not appealing professional future. Several studies have reported as the lack of perceived relevance is the main reason for low interest in

✉ Elena Macerata
elena.macerata@polimi.it

¹ Department of Energy, Politecnico di Milano, Piazza L. da Vinci 32, I-20133 Milano, Italy

² METID, Politecnico di Milano, Piazza L. da Vinci, 32, 20133 Milano, Italy

³ Department of Chemistry, University of Helsinki, Helsinki, Finland

⁴ Department of Environmental Sciences, Jožef Stefan Institute, Jamova cesta 39, 1000 Ljubljana, Slovenia

⁵ Institute of Radioecology and Radiation Protection, Leibniz Universität Hannover, D-30419 Hannover, Germany

⁶ Department of Nuclear Chemistry, Czech Technical University, Prague, Czech Republic

⁷ Division of Nuclear Chemistry and Industrial Materials Recycling, Department of Chemistry and Chemical Engineering, Chalmers University of Technology, 412 96 Gothenburg, Sweden

science study and carrier [1, 2]. In addition, younger generation perceive these disciplines related to radioactivity and in general nuclear industry as something to be afraid of.

Consequently, in the recent years, the availability of few engaging curricula and few career prospects in NRC, along with a misperception of this subject and a low awareness of its relevance, is causing a serious lack of interest among the young generation and consequently of NRC expertise in many parts of the world [3–6]. Indeed, the missed turnover due to retirements of the skilled workforce and the decreasing in the recruitment of newcomers is leading to a serious shortage in NRC expertise.

In this context, an educational approach based on a Massive Open Online Course (MOOC) has been selected as a way to (i) increase students' awareness about the relevance of a controversial and specialized discipline such as NRC, (ii) clarify fears and misconceptions about/towards anything that is “nuclear” and (iii) increase the number of students in NRC programmes and carriers [7, 8]. A MOOC course could be easily adapted to spread knowledge on different topics by addressing different target groups and going into the required level of details. Furthermore, the MOOC course is open and available online, so that provides the ability to reach massive number of students, worldwide [9].

The present paper describes the development process of a MOOC dedicated to explaining what NRC deals with and how often NRC competences are routinely used in the progress of our everyday life. The research aims at evaluating its impact and at analyzing the feedbacks collected by specific survey proposed to the users during the first MOOC editions.

The MOOC “Essential Radiochemistry for Society”

Design process

The MOOC titled “Radiochemistry for Society” has been designed and 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 heterogeneous composition of the group, their different backgrounds, branches of research and approaches in teaching, naturally required a time for alignment between the experts of the contents and the experts in MOOC designing and production, as well as a general agreement on some relevant course characteristics among the technical experts. These difficulties have been faced by giving the full responsibility of the process to a unique leading partner that supported colleagues in ensuring formal and structural uniformity.

The design of the MOOC started from a careful analysis of the target audience and the context in order to develop a completely online learning path aimed at achieving effective awareness and lasting knowledge, while maintaining a high degree of user involvement.

The main 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 time needed to acquire a basic comprehension of such a difficult discipline, bachelor students have been selected. Stimulating students during their Bachelor's degree could lead them to enroll in a Master's program in NRC. After the target group identification and the context analysis, the general didactical goals and the learning objectives have been identified to address the target needs. Such a methodological approach is described in the pedagogical framework, according to which the MOOC has been developed [10].

Then a Table of Contents has been filled in, according to the logic of the application areas: Radiochemistry “for the environment”, “for health”, “for industry”, “for nuclear energy”, “for society”, so that it is easier for users to understand why the NRC is useful with respect to the fields in which it is applied, highlighting what the consequences of each application are in terms of advantages and disadvantages. The MOOC is organized in the typical weekly structure, subdivided modules and lessons. The amount of content in each week has been calibrated to make the course manageable: each week corresponds to an estimated learning time, which can however be subdivided according to the number of modules, tuned to meet the students' availability.

In particular, the first lesson of each module represents an “immersion” in a simple everyday situation that apparently has nothing to do with NRC: everyone can recognize daily actions and objects. 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 nor introduces technical lexicon, it has the only objective to make the user aware of the involvement of radiochemistry and nuclear chemistry behind that situation. This easy explanation does not require 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 students to apply the acquired competences and skills as well as check their understanding. A useful links section, containing web links to freely available strengthening materials or relevant institutional websites, has been added to help users follow personal learning paths and further develop their NRC knowledge. A final assessment quiz, by attributing a score, enables the users to get the Certificate of Accomplishment.

Different lesson formats have been chosen: videoclips, articles, infographics, quizzes, exercises and links to external resources. Particular care was given in the selection and creation of images, tables and schemes.

MOOC syllabus

The MOOC is divided into five macro themes (so called “Weeks”), highlighting all possible applications of radiochemistry and nuclear chemistry for each specific area: Environment, Health, Industry, Nuclear Energy and Society.

The first Week on radiochemistry for the environment introduces the student to natural radioactivity by defining several basic concepts such as what is a radionuclide and a radioactive decay. Then, the student becomes aware of the production of artificial radionuclides by nuclear fission or particle accelerators, as well as the presence of abnormal concentrations of natural radionuclides, TENORMs (Technologically Enhanced Naturally Occurring Radioactive Materials), as consequence of anthropogenic activities. The students can 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.

Week 2 describes the 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 the industrial applications is completed by introducing the

polymer radiation chemistry and by explaining how it has been exploited over years to improve materials properties and produce innovative materials for high-tech applications.

The more obvious application of NRC in the 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. The whole course consists of 152 lessons, comprising 52 videos, 23 infographics, 34 exercises/quizzes and 33 articles, and the estimated effort to complete each week is about 6 h. The MOOC “Essential Radiochemistry for Society” is available on <http://www.pok.polimi.it> since 2020. Thanks to the financial support of the H2020 A-CINCH project, the MOOC editions are continuously monitored, maintained and enriched. In particular, live webinars, held by experts from prestigious universities and research centers, have been organized for the purpose of keeping the course updated on both the most interesting aspects of NRC and cutting-edge scientific research. These live webinars series, also called CINCH Talks, enriches the MOOC by synchronous moments during which the students could interact with external experts and discuss with them their most advanced research. The events are recorded and collected in a dedicated YouTube channel.

First MOOC editions

The first edition of the MOOC was a 3-months pilot edition, launched on June 2020 with the main aim to verify the MOOC effectiveness, the contents clarity and completeness, as well as to highlight critical aspects. The annual editions started just after the MOOC pilot edition in September. The first yearly edition lasted from September 2020 to August 2021 and the second one started on September 2021 and is still ongoing.

Fig. 1 Answers to some of the questions of the final questionnaire provided to students

Question: After completing the Week, what level of knowledge did you acquire?

	I've gained enough knowledge to explain the subject to other people	I understood the main topics and I'm able to understand general situations related to them	I only remember some of the main topics	Percentage of students who have spent less time than average on MOOC (1-2 h)
Week 1	50 %	45.5 %	4.5 %	8.7 %
Week 2	38.1 %	38.1 %	27.8 %	4.8 %
Week 3	38.1 %	42.9 %	19 %	14.3 %
Week 4	40.9 %	50 %	9.1 %	13.6 %
Week 5	31.8 %	45.5 %	22.7%	22.7 %

Question: Did you encounter any difficulties in understanding the topics presented in this week?

Week	Yes (%)	No (%)	Week	Difficulties
1	34,8	65,2	1	technical terminology not properly introduced complex concepts not properly introduced or explained too deep level of details with respect to pre-requisites
2	52,4	47,6	2	complex concepts not properly introduced or explained too deep level of details with respect to pre-requisites
3	42,9	57,1	3	technical terminology not properly introduced complex concepts not properly introduced or explained too deep level of details with respect to pre-requisites
4	27,3	72,7	4	complex concepts not properly introduced or explained too deep level of details with respect to pre-requisites
5	36,4	63,6	5	complex concepts not properly introduced or explained

Results and discussion

Pilot edition

Concerning the pilot edition, the quantitative data automatically collected by the platform, the qualitative data collected through customer satisfaction and the personal data collected through the initial survey showed that a sample of 203 users, mainly 20–25 years old students in scientific areas, from 20 different Countries all around the world followed the pilot MOOC edition, achieving an outstanding percentage of users (25%) that have completed the course and obtained the Certificate of Accomplishment [11].

To assess the MOOC effectiveness, content clarity and completeness, as well as to highlight critical aspects, a small group of 50 students at Politecnico di Milano were asked to attend the whole MOOC, get the certificate and answer to focused questionnaires on workload, level of knowledge acquired, interest aroused, lesson formats, difficulties encountered, contents, quizzes, and so on. The analysis of the collected data, together with the results obtained by the focus group, enabled us to derive further useful information.

After the completion of each of the 5 Weeks, students were asked to complete the related questionnaire and to use a video tagging tool to express their appreciation on some parts of some selected videos in terms of clarity, effectiveness and added value. Students declared to have devoted

on average 4.2–5.3 h to complete each Week, judging the workload coherent with what suggested. Similarly, the requested pre-requisites were considered enough to understand the course.

A relevant percentage of students (30–50%, see Fig. 1 top) stated that they gained enough knowledge to be able to explain the subject to other people, and just as many stated that they understood the main topics and were able to understand general situations related to them. However, the time dedicated to the study impacts on the level of knowledge acquired, as shown in Fig. 1 for Weeks 3 and 5, as well as the complexity of the topic and the level of details provided as the case of Week 2. Indeed students (42–52%) highlighted to have found more difficulties in understanding the topics in Weeks 2 and 3, due to the presence of very complex concepts not properly explained or not enough discussed, the use of a technical terminology not properly explained and a too deep level of details with respect to the pre-requisites. The explanation of a complex concept by an infographic was somehow considered not enough to get a full understanding of a concept, while video lessons were generally positively evaluated. The video tagging activity enabled to highlight that relevant keywords in the background of a video are very helpful, as well as laboratory images and practical examples. Concerning the organization of learning materials, students appreciated the alternation of

Fig. 2 Average score achieved by users for each module and week during the pilot edition

MOOC		Average score
Week 1: Radiochemistry for the environment		0.93
M1	Natural Radioactivity	0.91
M2	Radioactivity from anthropogenic activities	0.90
M3	Environmental remediation	0.98
Week 2: Radiochemistry for health		0.815
M1	Nuclear medicine	0.78
M2	Sterilization by Ionizing radiation	0.85
Week 3: Radiochemistry for industry		0.895
M1	Tracer technology	0.88
M2	Radiation processing	0.91
Week 4: Radiochemistry for nuclear energy		0.897
M1	Reprocessing of spent fuel	0.89
M2	Confinement and Waste Management	0.85
M3	Decommissioning of nuclear/industrial plants	0.95
Week 5: Radiochemistry for society		0.855
M1	Cultural heritage	0.91
M2	Nuclear forensics and proliferation	0.80

the different lesson formats (videos, infographics, articles) to explain topics, with intermediate assessment moment in the form of quizzes, and the presence of guided exercises to apply competences. Too long articles describing too many details should be avoided or substituted with videos.

Concerning exercises and quizzes, students evaluated them well calibrated with respect to the contents, but great attention must be devoted to well formulate the question.

Some considerations could be done considering the average score achieved in the final exam. It is equal to 0.91/1, supporting the effectiveness of the overall MOOC materials. However, by considering the average score achieved in each week or module, some differences arise. Figure 2 reports the average score achieved in each module and week: we have considered the results achieved by all the users that have attempted the exam even if they did not complete the MOOC. The collected scores could be analyzed by considering some of the features that characterize each module, such as the topics dealt with, the different lesson formats used, etc.

Thinking to the grades achieved, it is possible to state that modules showing a lower average grade are characterized by:

- the presence of complex concepts and/or several technical details, such as the Module on Nuclear Medicine, Sterilization and Tracer technology;
- few video lessons, such as the Module on Confinement and waste management;
- complex concepts presented as infographic, such as in the Module on Nuclear forensics and proliferation;
- the lack of practical examples;
- the presence of long articles with too many details.

On the contrary, modules with the highest average grade are those in which videos lessons were widely used, there are a lot of practical examples, images from laboratory work and exercises, that resulted to be effective in consolidating the knowledge.

Concerning the impact of the MOOC on their personal and professional experience, the data collected highlighted that the interest in the topic and the level of engagement achieved are paramount to captivate the users and thus to drive their future involvement.

MOOC Promotion and communication

To achieve our goals, it was not enough to create a well-designed and high-quality course, it must be promoted appropriately in order to actually reach a large number of students. In this perspective, the availability of the MOOC on NRC has been advertised by preparing an explicative flyer with the main details and the link to the resource and by sharing it by email. First, the course has been promoted at project level, by asking to the project Partners to share the information with their students at universities or young colleagues of Research Institutes, and with personal and professional contacts. Later, the flyer has been shared on institutional websites, channels, and social networks by the project Partners. Finally, participation in scientific conferences also enabled the course to be disseminated to an even wider international audience. By means of these promotional actions, we were able to reach mainly European students and teachers, but also some people from other continents.

First annual edition

The first annual edition was attended by 197 users, mainly belonging to the target group (20–25 years old students in scientific areas), from 29 different Countries all around the world, the majority from Italy (44%), Finland (9%), Slovenia (7%) and Kazakhstan (5%). The gender distribution seems to be maintained: among the 190 MOOC users, 41% are female and 59% are male, interestingly demonstrating a comparable interest towards NRC among males and females. The percentage of users that have completed the course is still appreciable for a so specialized MOOC: 19% obtained the Certificate of Accomplishment, with a high average score in the final exam (0.914/1, equal to that observed in the pilot edition). The high scores achieved thus confirm the effectiveness of the pedagogical framework to reach the learning objectives and the adequacy of the contents.

Data collected let us observe the period of time in which students were active by watching videos or answering quizzes. Within the period corresponding to the first academic semester the most active users come from Finland, Slovenia and Kazakhstan, while Italians increase significantly in the second semester. This supports the idea that the MOOC usage is mainly driven by teachers, that propose the MOOC to the students within specific courses by a flipped classroom approach.

Second annual edition

The second annual edition of the MOOC started in September 2021 and is still ongoing. After 8 months, 113 users,

well gender balanced, are enrolled from 20 different Countries worldwide. 17% of the users obtained the Certificates with an average score in the final exam of about 0.9/1. These numbers seem to confirm a constant participation and interest in the proposed MOOC.

Challenges, strong points, weakness

The goal of the research, i.e. the realization of a MOOC dealing with NRC within a wide and heterogenous partnership to attract European students towards these disciplines, was very challenging. Many factors have to be taken into account to succeed in this task. Once selected the most appropriate target group, differences among members of the target audience in the different European Countries needed to be considered, as well as a suitable engaging pedagogical framework to offer an effective learning experience.

The data and feedback collected from the first MOOC editions enabled to bring into focus the main positive features of this course as well as its weaknesses. The course is completely manageable based on the availability of the student who can take the course as he or she sees fit over the availability span of the edition (a year). The content can be leveraged individually. In addition, the learning path and the lessons format resulted to be effective in letting the user reach a good level of knowledge and acquire new skills, as demonstrated by the average scores achieved throughout the editions.

In general, the work done made valid teaching materials on NRC from accredited sources available to professors and students.

An important and not to be underestimated part of this work is promotion. Being a very niche discipline, the promotion of a course on NRC is even more complex. Specific actions have been developed to allow for greater dissemination not only among the direct users, i.e. the students, but also among the teachers.

Conclusion

Thanks to the fruitful collaboration of academic experts, digital learning team (and media production team), the MOOC “Essential Radiochemistry for Society” is available for anyone.

The positive feedback obtained from the focus groups of students belonging to the target audience, as well as from the high average scores achieved by the students that attempted the exams, made it possible to draw preliminary conclusions about the effectiveness of the course. However, this goal could only be monitored and confirmed through future editions. Surely, feedback from the first edition highlighted the

potential of this course and how its continuous monitoring and improvement allows it to be kept up to date over time.

In general, the production of a MOOC is a very onerous activity. Universities and research centres could hardly take on such a burden, if not with an external financial support. This is particularly true in the case of the MOOC on NRC, whose target group is intrinsically a small group due to the specificity of the themes dealt with. However, the efforts done have made well-designed learning materials on NRC available to all, a first step to share knowledge. Indeed, this course could be potentially exploited in several ways and contexts. To make this happen, a more effective promotion among students and teachers and the proposal of MOOC usage models could enable to reach a wider audience and to improve the MOOC impact.

Acknowledgements This work was financially supported by the European Commission within the H2020 MEET-CINCH Project (grant agreement No 754,972, <https://www.cinch-project.eu>) and the H2020 A-CINCH Project (grant agreement No 945,301) funded by Euratom research and training programmes 2014–2018 and 2019–2020. This work was presented at the 19th Radiochemical Conference (Rad-Chem 2022) held in Mariánské Lázně, Czech Republic, on 15–20 May 2022.

Funding Open access funding provided by Politecnico di Milano within the CRUI-CARE Agreement.

Declarations

The authors have no relevant financial or non-financial interests to disclose. The data underlying this article will be shared on reasonable request to the corresponding author.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate

if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

1. Johannes Perna, Gareth TW, Law, Ranjan S (2021) J Chem Educ DOI. <https://doi.org/10.1021/acs.jchemed.0c01216>
2. Stuckey M, Hofstein A, Mamlok-Naaman R, Eilks I (2013) Stud Sci Educ 49(1):1–34
3. IAEA (2006) Risk management of knowledge loss in nuclear industry organizations. International Atomic Energy Agency, Wien
4. IAEA (2018) NUCLEAR KNOWLEDGE MANAGEMENT CHALLENGES AND APPROACHES. Wien: PROCEEDINGS SERIES;
5. IAEA (2017) Knowledge Loss Risk Management in Nuclear Organizations. IAEA Nuclear Energy Series, Wien
6. Boyles JE, Kirschnick F, Kosilov A, Yanev Y, Mazour T (2009) Int J Nuclear Knowledge Management 3:2:125–136
7. IAEA (1998) Experience In The Use Of Systematic Approach To Training (SAT) For Nuclear Power Plant Personnel IAEA-TEC-DOC-1057, Wien,
8. EUROPEAN COMMISSION, NFRP-11: Advancing nuclear education in Euratom Work Programme 2019–2020 (2018) p. 18
9. Kaplan AM, Haenlein M (2016) Bus Horiz 59:441–450
10. Concia F, Macerata E, Mariani M, Negrin M, Sancassani S(2019) Proceedings of EMOCs 2019: Work in Progress Papers of the Research, Experience and Business Track. http://ceur-ws.org/Vol-2356/experience_short3.pdf
11. Macerata E, Negrin M, Concia F, Mossini E, Magugliani G, Sancassani S(2020) IL NUOVO CIMENTO 43 C, 151–158

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.