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Open self-paced introductory course in nuclear engineering – How to guarantee student learning

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A B S T R A C T

Ease of access to various free educational resources on the internet has often the disadvantage of resulting in scattered and fragmented knowledge and skills. Students "pick and choose" what they believe to be relevant for their learning but lack the necessary overview of the field to select those resources adequately and properly. This also applies to nuclear engineering, for which educational materials can be found on the web. Although some Massive Open Online Courses exist in this area, access to those often requires registration, or those courses are given during limited times. Following the Open Educational Resources initiative, there was thus a need to develop educational materials that are truly open and freely accessible to all, while guaranteeing student learning. This paper reports on efforts along those lines, which resulted in the planning, development, implementation and offering of three self-paced open course modules in nuclear engineering. Through a careful course design and use of the various features of a specific educator-to-educator Learning Management System, the students are guided through highly structured course materials capitalizing on a diversity of activities proposed to the students. Through self-assessment competence tests, the students can measure their mastery of the field, ultimately resulting in the delivery of a certificate of successful completion of the modules. This paper also presents, from a teacher's perspective, some lessons learnt that could benefit other teachers interested in embarking on similar endeavours.

1. Introduction

Access to clean, affordable, and reliable energy sources is one of the biggest challenges of our times. In this respect, electricity is an essential commodity from which our societies benefit enormously in all aspects of daily life (Smil, 2017).

Due to the growing earth population and the need to drastically reduce our CO2 emissions, an extensive development of carbon–neutral energy sources is required, combined with energy efficiency measures and energy storage capabilities. A variety of energy sources and technologies needs to be used to meet our mitigation goals (IPCC, 2023).

As each energy source has its advantages, disadvantages and limitations, a more balanced view and understanding of each technology is key for making best use of it and for efficiently combining it with other technologies.

As one of those sources, nuclear power represents today about 10 % of the world's electricity, with very large variations from country to country (with some countries relying on up to 70 % on nuclear power) (World Nuclear Association, 2023a, 2023b). With more than 440 reactors in operation and more than 50 under constructions, this technology represents an essential pillar in the production of carbon-free electricity and will remain so in the decades to come (World Nuclear Association, 2023a, 2023c).

Despite the extensive deployment of nuclear power in the 1970ies and 1980ies in Europe, USA and South-East Asia when our societies were profoundly more technology enthusiastic (Kaijser et al., 2019), the nuclear energy transition never occurred (Smil, 2017). Fears of nuclear accidents after the Three Mile Island accident in 1979 in Harrisburg, Pennsylvania, USA created, although no contamination and no casualties, a profound anti-nuclear movement that considerably slowed down the constructions of new nuclear units. This was enhanced by the Chernobyl accident in 1986 in Pripyat, former USSR, and by the Fukushima Dai-ichi accident in 2011 in Fukushima, Japan.

The complexity of such a technology-intensive power source also resulted in erroneous information spread about this technology, further contributing to the fear of nuclear accidents. Explaining, to a wide audience, nuclear power technology, its advantages and disadvantages, as well as the societal, ethical and economic implications of the use of nuclear power, is key in presenting such a technology in a more balanced and neutral manner.

Although many resources can be found on the internet about nuclear technology, the ones openly accessible are most often of varying quality. Furthermore, such resources are scattered through the web without any clear structure. "Cherry-picking" information in this manner results in

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erroneous understanding of the relations existing between different concepts and in poor learning. On the other hand, Massive Open Online Courses (MOOC) on nuclear power exist and have highly structured contents. But they often require registration, i.e., the need to enter personal data to get access to the contents. This extra step represents an extra hurdle, thus preventing the instantaneous and wide use of such resources.

The work reported hereafter has for objectives to precisely provide a source of openly, free, reliable and accurate information to those who desire to learn more about nuclear power, while guaranteeing student learning. The resources thus developed are part of the Open Educational Resources (OER) movement. For this purpose, a specific educator-to educator "Learnify[1]" Learning Management System (LMS) allowing collaboration, co-creation as well as the delivery of open but structured content was used. The LMS has embedded features making it possible for the student to themselves test their understanding and to be provided instantaneous feedback in case of mistakes/erroneous answers provided. The different activities aim at securing the proper transfer of competences, i.e., knowledge, skills and, to some extent, attitudes (International Atomic Energy Agency, 2006; European Union, 2018).

In the following of this paper, the pedagogical format of the resources is first presented, together with the main features of the LMS. Thereafter, an overview of the developed resources is given, focusing on the contents and structure of the resources, with some examples given. Finally, some lessons learned from the development and student use of those resources are provided.

2. Pedagogical set-up

In order to guarantee efficient student learning, the development of the resources and their potential use by the students were carefully planned. A flipped classroom philosophy, which is briefly introduced hereafter, was adopted. The LMS and its main features are then introduced.

2.1. Flipped classroom

In a flipped classroom, preparatory work in forms of reading materials and watching videos or video lectures is typically given to students before they are exposed to activities requiring more engagement and participation (Bishop and Verleger, 2013). The essence of flipping is to condition the students to such activities, during which "active learning" (also called in everyday's jargon "learning by doing") takes place. Active learning techniques were demonstrated to lead to more efficient student learning and to increased student performance (Freeman et al., 2014). In Bloom's revised taxonomy of the cognitive domain (Anderson et al., 2000), the preparatory work targets low-order cognitive skills, during which the student need to remember and understand the concepts newly introduced to them. As learning is individual, letting the students choose the pace at which they learn those concepts (self-paced learning) is often beneficial. Thereafter, activities capitalizing on the learned concepts are proposed to the students. The aim of those activities is to promote student high-order cognitive skills, so that they apply, analyse and evaluate the learned concepts, and potentially produce new or original work from those concepts.

Designing activities targeting cognitive skills higher than just recalling the learned concepts is best executed with teacher's supervision. Flipping can often be seen as removing the traditional delivery of knowledge from the classroom during which very little teacher support is required. This thus makes room for more engaging teacher-supported activities, for which teacher's help is fundamental.

The learning resources reported in this paper make use of the flipped classroom approach. There is nevertheless one fundamental difference compared to a traditional implementation of a flipped strategy in the present case: the learning resources are entirely provided online and in self-service. This means that the more advanced and engaging activities are also offered without direct teacher support. This required designing activities that the students could take on their own and on which they could be provided automatic feedback in case of both correct and incorrect answers. Although preparing the learning resources for the preparatory work is time consuming, the preparation of the more engaging activities is far more time consuming and challenging for the teachers. Examples of all those resources are given in Section 3.3.

It should be noted that discussion sessions with the teachers can be offered as a complement, thus re-introducing some interactivity with and direct support from the teacher.

2.2. EEDA initiative and learnify repository

The learning material is presented via the EXPLORE Energy Digital Academy (EEDA) environment. The EEDA is an "educator-to-educator" network that has come out of a combined work from Erasmus + Capacity Building in Higher Education projects. This collaboration was initiated in the project EUSL-Energy[2] in 2020 between four universities in Sri Lanka and three in Europe. It was extended via the EUBBC-Digital[3] project (8 universities in Latin America and 7 in EU in 2021) and recently through 3 more projects in Latin America and Africa. These projects have presently 42 university partners in 20 countries in 4 continents as partners, plus a number of other teachers collaborating in different ways.

The main perspective of the EEDA is the educator collaboration, allowing for co-creation and re-use of learning resources in a "global-but-local" perspective with emphasis upon student-centred education and challenge-driven learning. The base for the concept is the breakdown of all learning material into "modules" that usually are less than 5 Estimated Learning Hours (ELH) each, as seen on the left hand-side of Fig. 1. The collaboration is performed within Creative Commons and as such all the modules can be copied and modified for any specific not-for-profit purposes. The modules can then be combined into "lessons", "topics" and "courses" in different ways. For this to be useful in an academic environment, each module must have a set of metadata that clearly describes, and associates with, elements that are part of a university course. This starts with Intended Learning Outcomes (ILOs), and includes study level (European, and/or National, Qualification Framework level [EQF]), pre-requisites, grading criteria, credit volume, etc., as can be seen on the right hand-side of Fig. 1. The ILOs are identified by the EQF-2018 criteria of Knowledge, Skills, Responsibility & Autonomy as well as Bloom's Taxonomy levels, in exactly the same way as any academic course. The difference is here that the teacher has to reflect upon these on the "module-level" compared to what is usually done on the "course-level".

The result of such module development is a "Subject Area" structure and a "mosaic" of modules created by many different teachers (as the example shown in Fig. 2). As exemplified in Fig. 3, all modules are collected in a common repository, called "Learnify". They can be seamlessly added, and retracted, from any individual local environment a teacher might work in (although that, for reuse and collaboration, they must be developed as per the EEDA structure). The system allows for a very easy reuse, co-creation and copying of the modules. The incorporated "Quality Improvement Process" ensures a basic self-evaluation (resulting in a basic "badge") as well as improved quality through peer and student reviews, as seen in Fig. 4.

The "student-centred" concept is built up towards the "Flipped Classroom" through the process of automatically corrected questions and exercises, as illustrated in Fig. 5, such that a teacher can secure that

[1] https://learnify.se/en/.

[2] https://euslenergy.com/.

[3] https://www.eubbcdigital.com/.

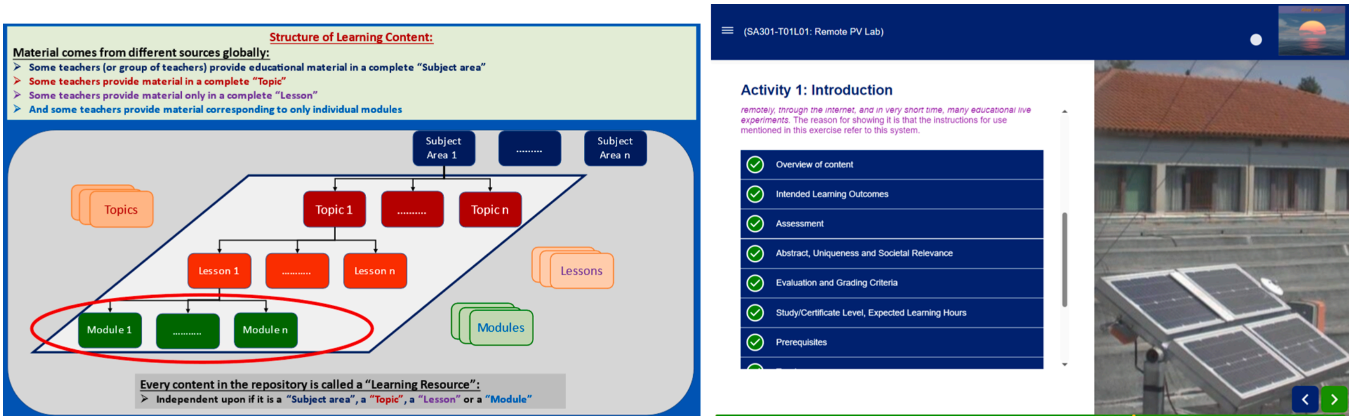

Fig. 1. Structure of the EEDA concept (left figure) and of the academic metadata in each module (right figure).

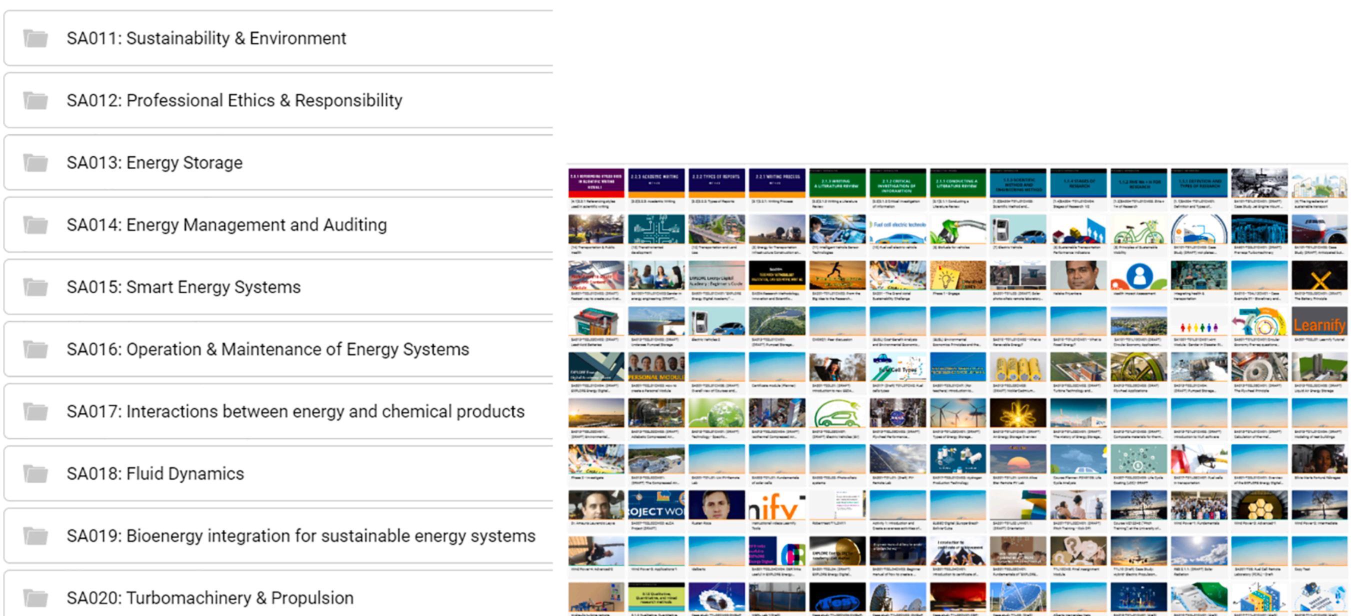

Fig. 2. Presentation of individual Learning Modules in "Subject Areas" and broken down into a "mosaic" form. The Subject Areas are used for characterization of the modules in a searchable way.

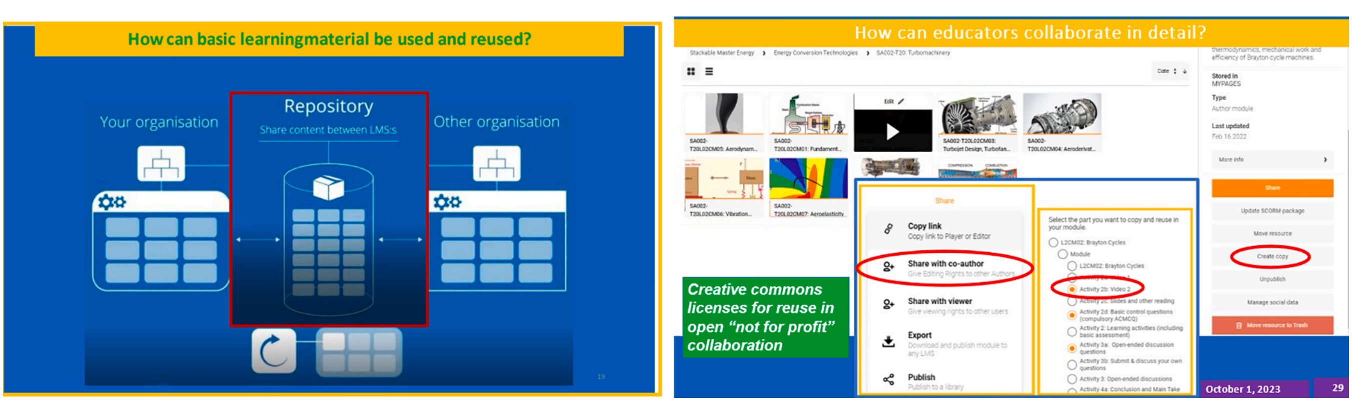

Fig. 3. Illustration of the Learnify repository: adding and retracting modules from different storage systems into the Learnify repository (left figure); sharing, co-creation and copying complete or part of a module (right figure).

the learner has passed the basic tests before being allowed into any eventual discussions with a "live instructor". It is furthermore directed towards challenge-driven learning (and has a set of basic such modules that any teacher can take over "as is" into his/her own challenges) such that different learners might select different expertise towards solving the challenges. As such, the concept allows an academic program to

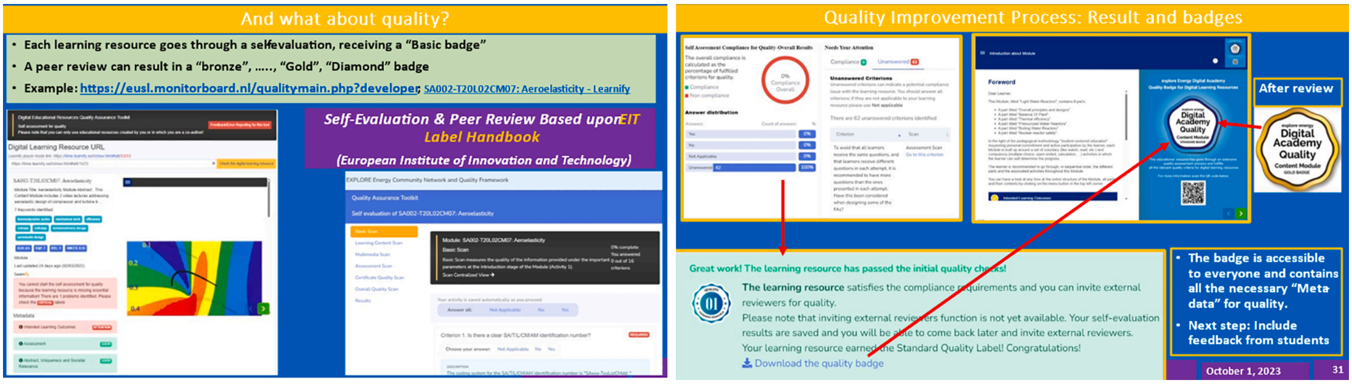

Fig. 4. Self-evaluation and peer review system of modules, resulting in enhanced quality through co-creation. In the left figure, the Quality Improvement Process (QIP) automatically identifies, as a first step, if the "academic metadata" is properly presented in a coherent way. After this, there is a significant "check-list" of items the author has to consider in a "Yes/No" perspective. Once the self-evaluation is performed (right figure), the QIP system suggests (from the internal network) a few reviewers who have similar interests. The QIP also has an option for inviting other external reviewers. Upon positive review results the author receives a "higher-level badge"(in the example a "Gold Badge") which can be uploaded in the module.

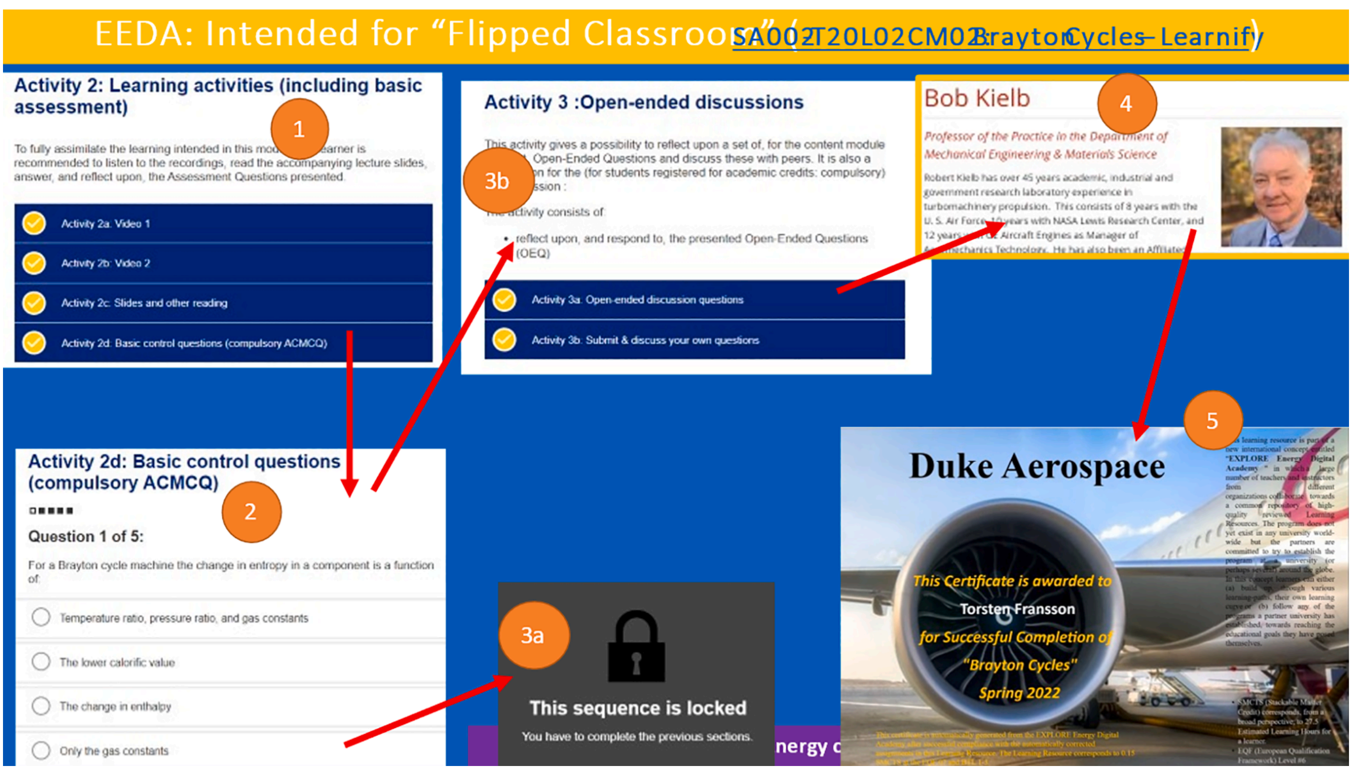

Fig. 5. "Flipped Classroom" perspective to ensure that the learners correctly answer a number of assignments to receive a certificate or being allowed into any eventual "live instructor-led workshops". The area labelled "1" illustrates a few activities the learner has to perform to learn the material. The area labelled "2" shows an example of a set compulsory questions for a formative assessment inside the module. If these questions are not answered properly, it is not possible to proceed to participation in the live discussions with the instructor (area labelled "3a"), If the questions are answered correctly, the learner can proceed to (for example) participate in live, instructor-led discussions by reflecting upon a few open-ended questions, and also preparing own questions (area labelled "3b"). These are then discussed with the instructor in the "live session" (area labelled "4"). After full completion of the module, the learner has the option to receive a "Certificate of completion" (area labelled "5").

have more elective and less compulsory courses, with the possibility to allow students with more diverse backgrounds to get together to solve the specific challenge at hand. An added feature is also the (soon to be available) set of remotely controlled laboratory exercises that can be used by students globally, as presented in Fig. 6.

The system is set up such that any learner can access any of the modules as soon as the url link is available. It is also possible to create a course (academic, professional, micro-credential, …) very simply in the EEDA OpenEdX concept by simply adding (via SCORM or LTI) the corresponding modules in a selected sequence, thus allowing also for a progress control of each individual student.

3. Overview of the developed resources

In the following, a brief overview of the topics covered by the course is given, thereafter followed by a description of the typical structure of the associated learning resources. Finally, an example of such a typical structure is also presented.

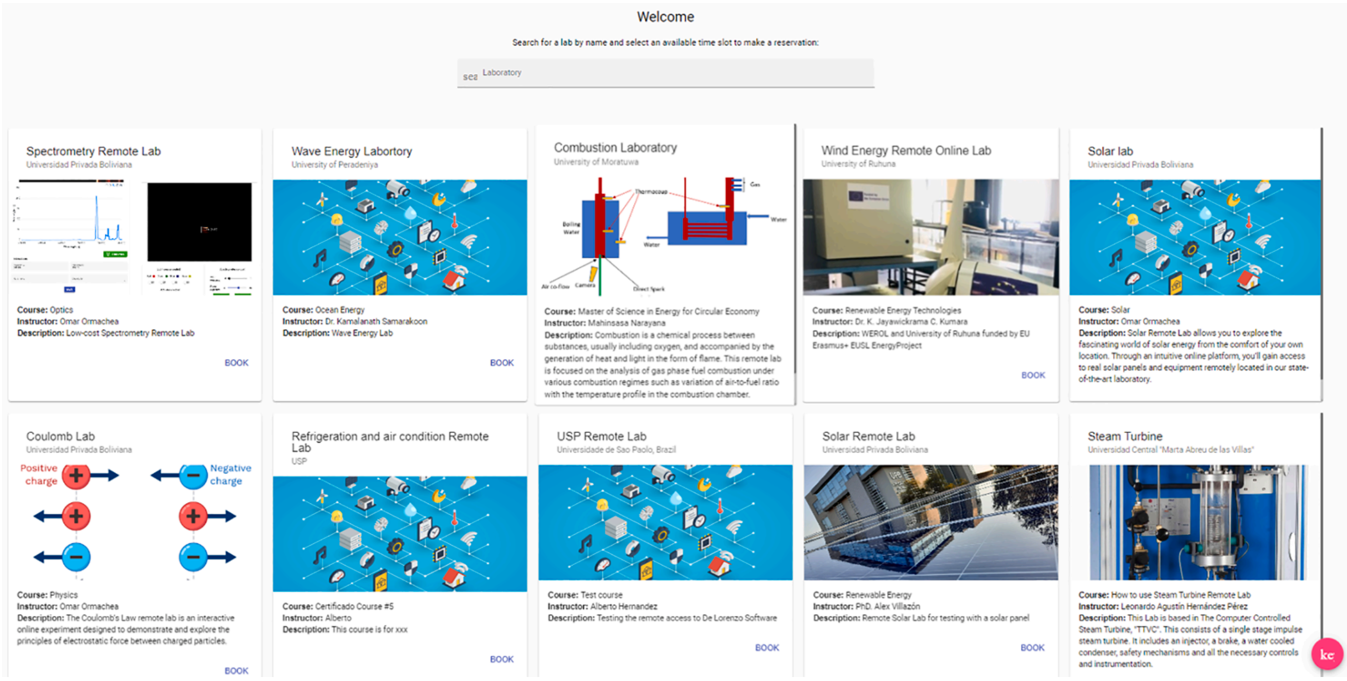

Fig. 6. Booking system for the remotely controlled laboratory exercises.

3.1. Contents of the modules

The course, titled "Introduction to nuclear engineering" is made of three modules, each having several chapters. A BSc in Engineering or similar knowledge is required to best follow the modules. Nevertheless, all principles are derived from scratch, thus allowing any engineering student to comprehend the presented concepts. The advantage of the "flipped classroom", as developed in the EEDA concept, is that any learner might experience the education without any formal entry requirements.

The first module, labelled "Nuclear power, an old story" and available at https://time.learnify.se/l/show.html#att/1D2q, aims at explaining the underlying principles of nuclear reactors for the purpose of understanding the history of the development of nuclear power. The module requires 5 ELH of work from the students and is made of three chapters:

- A chapter titled "Elementary concepts in nuclear physics" covering the following topics/concepts: constituents of matter, nuclear reactions involving neutrons, radioactivity.
- A chapter titled "Working principles of nuclear reactors" covering the following topics/concepts: fission reaction, prompt neutrons, delayed neutrons, precursors of delayed neutrons, chain reaction, capture reaction, leakage, scattering reaction, isotopes, fissile species, fissionable species, fast reactors, thermal reactors, neutron slowing-down/moderation.
- A chapter titled "History of world nuclear power development" covering the following topics/concepts: first natural nuclear reactor, first research reactor, the Manhattan Project, first nuclear-powered submarine, first nuclear power station for electricity production, first commercial nuclear power station for electricity production, Generation-I reactors, the Windscale accident, Generation-II reactors, the Three Mile Island accident, the Chernobyl accident, the Fukushima Dai-ichi accident, Generation-III and III + reactors.

The second module, labelled "Nuclear reactor technology" and available at https://time.learnify.se/l/show.html#att/v1rL, aims at explaining how a nuclear reactor works with emphasis on Light Water Reactor (LWR) technology. Both the phenomenological and engineering aspects of nuclear reactors are covered. The module requires 20 ELH of work from the students and is made of 11 chapters:

- A chapter titled "Electricity generation" covering the following topics/concepts: steam power cycle, steam turbines, generator, condenser, pumps, heater.
- A chapter titled "Reactor generations" covering the following topics/concepts: Generation-I reactors, Generation-II reactors, Generation-III/III + reactors, Generation-IV reactors.
- A chapter titled "LWR technology" covering the following topics/concepts: overall principles and design, PWR specifics, BWR specifics.
- A chapter titled "Thermodynamic analysis of LWRs" covering the following topics/concepts: reminder about the steam power cycle and balance of plant, thermal efficiency.
- A chapter titled "Neutron cycle", covering the following topics/concepts: neutron cycle, six-factor formula, thermal utilization factor, thermal fission factor, fast fission factor, resonance escape probability, slowing-down non-leakage probability, thermal non-leakage probability, infinite multiplication factor, effective multiplication factor, reactivity, critical/subcritical/supercritical systems.
- A chapter titled "Fuel depletion", covering the following topics/concepts: evolution chains, fission products, major actinides, minor actinides, burnup.
- A chapter titled "Reactor control", covering the following topics/concepts: soluble poison, burnable poisons, control rods, integral control rod worth, differential control rod worth, core flow reactivity effect, void coefficient of reactivity.
- A chapter titled "Reactor dynamics", covering the following topics/concepts: rapid changes in reactivity, slow changes in reactivity, feedback effects.
- A chapter titled "Reactor operation", covering the following topics/concepts: operating goals and constraints, In-Core Fuel Management, typical evolution of core properties.
- A chapter titled "Fundamental principles of reactor safety", covering the following topics/concepts: overall safety principles and reactor shutdown, engineering safety features.

- A chapter titled "Nuclear fuel", covering the following topics/concepts: nuclear fuel cycle and fuel utilization, nuclear waste.

The third module, labelled "Nuclear power, saving the world?" and available at https://time.learnify.se/l/show.html#att/x3Vl, aims at explaining the aspects of nuclear power to be considered in a climate mitigation perspective. The module requires 4 ELH of work from the students and is made of 5 chapters:

- A chapter titled "Nuclear fuel resources", covering the following topics/concepts: uranium resources, dependence on the fuel cycle strategy.
- A chapter titled "Proliferation risk", covering the following topics/concepts: definition of the risk of proliferation, proliferation risk of the various fuel cycle strategies.
- A chapter titled "Cost of electricity", covering the following topics/concepts: cost of electricity from nuclear power, comparisons with other electricity sources.
- A chapter titled "Risks", covering the following topics/concepts: definition of risk, health effects of past accidents.
- A final chapter titled "Wrap-up", giving some summary, take-aways and prospects on the use of nuclear power in a climate mitigation perspective.

3.2. Structure of the modules

Each module is made of a set of different chapters. The module starts with an overview of the different chapters. Thereafter, the intended learning outcomes in terms of knowledge, skills, and responsibility/autonomy are described. The students are then introduced to the way they will be assessed, evaluated and graded throughout the module. The number of ELH of work required from the students is also given, so that the students can appreciate the extent of the module and associated activities. Possible prerequisites to follow the module are also listed. Finally, the introduction of the module ends with a list of references associated to the module.

Within a module, each chapter follows the same structure, made of the following elements:

- An introduction listing the different concepts the chapter will present, together with the number of lectures and their duration. A link to download the slides associated to the videos is also provided.
- Thereafter, a series of video lectures intertwined with quizzes/small exercises is given. Whereas the video lectures present some concepts, the quizzes/small exercises focus on the application of those concepts. The students are given two attempts on each quiz/exercise and are provided with different feedback when they fail on the first attempt and when they fail on the second attempt. If the students fail on the third attempt, they are provided with the correct answer together with some explanations. Feedback/additional explanations are also provided when the students answer correctly. The quizzes/small exercises aim at assessing not only the transfer of knowledge, but also the proper development of skills. This is achieved by activities requiring the students to find procedures to solve tasks of increasing complexity. The automatic feedback the students receive help them to develop imitation, manipulation, precision, and articulation skills (International Atomic Energy Agency, 2006).
- The chapter ends with a series of open questions the student should answer directly on the LMS for self-reflection. The purpose of this series of questions is to force the students to conceptualize the various themes they were presented in the chapter and to summarize in their own words the key points of the chapter. Although this activity mostly targets high order cognitive processes, the students also need to develop different sets of attitudes of the affective domain (such as perceiving, valuing and organizing) (International Atomic Energy Agency, 2006).

At the end of a module, a summary of the main concepts presented throughout the different chapters is first given, followed by an anonymous survey on the content, value and workload of the module. Thereafter, a certificate of successful completion is automatically delivered, if the students have worked on each item of all chapters constituting the module (if the students have been issued credentials to access the module, their name will be stated on the certificate). On a voluntary basis, the students can also provide anonymous feedback and leave comments/see comments from others on a discussion forum (not monitored by the teachers). Finally, the students are offered the opportunity to download all free text answers they provided through the entire module.

Although there is a recommended sequence to follow the different chapters, the students can also jump between different chapters and between different elements within the chapters. Nevertheless, to be issued a certificate of successful completion of the module, the students must have worked on all chapters and all associated resources. The students can resume their work on a module at any time and thus do not need to complete everything at once.

3.3. Example of the developed teaching resources

To better exemplify the LMS and the associated resources, some illustrative examples of some of the developed teaching resources are given below.

Fig. 7 gives an example of a video lecture accessible through the LMS. All video lectures are made of slides recorded with the audio and video of the lecturer. To make it easier for students to understand the various concepts and explanations, the slides are annotated during the lecture by the teachers. This also increases student engagement with the presented learning resources. The students have the possibility to rewind the lecture at any time and to change the playing speed if they wish (between 0.75x and 2x). The slides were prepared with the objective to present the information in a clear and simple manner, for which the input from the teacher in form of audio/video complemented by on-screen annotations/derivations is required to fully comprehend the resources. As the module is openly accessible to all, the illustrations were either developed by the teacher or taken from freely usable media. In the latter case, the source of the media was clearly indicated on the slides.

An example of a quiz/small exercise is given in Fig. 8. Many alternatives of quiz questions exist on the LMS and were used throughout the modules: multiple choice questions, ranking alternatives, entering numerical values, selecting a part of a figure/illustration. As the purpose of the quizzes is to force the students to process their knowledge and apply it, the quizzes are often based on small numerical exercises the students should complete in order to find the right answer. The instructions provided in the quizzes, together with the feedback in case of both correct/incorrect answers, help the students at targeting high-order cognitive skills. Special attention was given to design the quizzes so that they are "failproof", i.e., only one possible and clear answer is possible, and the interpretation of the question and the derivation of the solution should be unique.

4. Lessons learned

In the following, some lessons learned from a teacher's perspective are given.

First and most importantly, the platform allows preparing and delivering a very structured learning environment to the students. This environment can be made of many diverse types of activities, both in contents and in format. The possibilities offered by the platform are endless, and it is up to the teacher's imagination and inventiveness to make the best use of all of them. Thanks to the structure the teacher develops, a logical path for studying is presented to the students, thus avoiding the possible fragmentation of knowledge often encountered in self-paced learning when the students seek for learning resources on

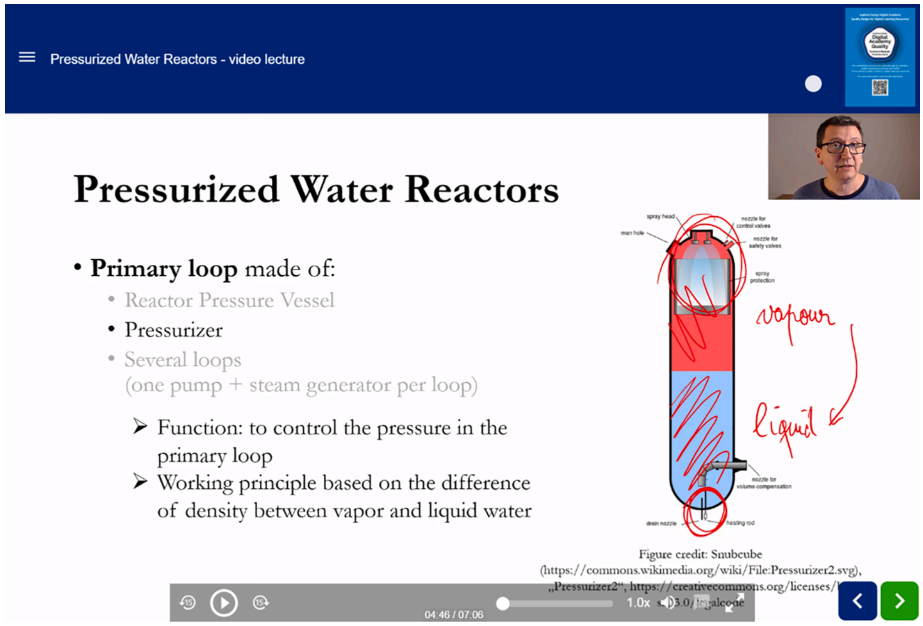

Fig. 7. Example of a video lecture.

their own. The activities testing student knowledge, understanding and skills are essential in guaranteeing that the learning resources have the expected effect/impact. In this respect, the possibility to embed automatic feedback depending on how the students perform is of great support to the students.

Developing pedagogical resources as the ones presented in this paper is nevertheless a very time-consuming process. Before actually developing the resources, a careful planning of the necessary actions is necessary. Those actions include the following steps, that can furthermore be categorized as either “normal course development work” (i.e., work required for any course development, irrespective of its format) or “online digital work” (i.e., work specifically related to the online self-paced nature of the course):

1. *Learning the LMS and its features – online digital work*. As not all LMS have the same capabilities, it is essential to get well acquainted with what the LMS can offer, so that the full potential of the LMS can be utilized and, most importantly, the learning resources can be designed taking advantage of those features. Possible limitations also need to be identified, so that one does not later spend time on developing learning resources that cannot be implemented on the LMS.
2. *Sketching the course activities – normal course development*. Based on the identified capabilities of the LMS, a sequence of learning activities must be created. Those activities are required to be aligned with the learning objectives of the modules, following the principles of constructive alignment (Felder and Brent, 2016). They also need to help the students process the contents of the modules while progressing in Bloom’s taxonomy, going from low-order to high-order cognitive skills. The teacher should develop a strategy for that purpose.
3. *Developing the course activities – normal course development*. This part typically involves creating supporting teaching materials: text, slides/presentations, audio/video recordings, quizzes and small exercises/assignments (that could be used to provide formative and summative feedback to the students), discussion themes for self-reflection, etc. In the present case, having modules to be used in self-service represents an additional challenge. As the teacher is not present to possibly provide additional explanations to the students, some automatic feedback must be implemented. For instance, in the quizzes and small exercises/assignments, feedback should be provided to the students in case of incorrect answers (and additional explanations could also be provided in case of correct answers). This requires some additional efforts from the teachers to think about all possible erroneous answers/reasoning paths students could propose. Furthermore, a unique and clear solution should exist for all assignments.
4. *Implementing and testing the activities on the LMS – online digital work*. In order to support student learning, a clear, intuitive and easy-to-understand structure must be implemented on the platform. The teacher has to make sure that students cannot “get lost” on the LMS. This requires making sure that all activities are correctly chained and that no error can occur when using the learning resources. This typically requires the teacher to test all resources as a student. In this respect, being in the student’s shoes is also a necessary step to appreciate the efficacy of the learning resources. This may require redesigning some of the activities proposed to the students.

Concerning the production of teaching materials, one may be tempted to create resources of very high standards, such as, e.g., producing video lectures in a professional recording studio with a green screen, etc. Although such resources are certainly well prepared and of professional appeal, their efficacy on student learning compared to resources produced using low-budget solutions might be questioned. For instance, a well-prepared lecture recorded on the teacher’s own computer and on-screen annotations might be sufficient. If the teacher has a clear message to deliver and a strategy to make sure the students are engaged, a low-budget lecture might be as efficient as or even more efficient than a high-tech solution.

Along the same line, the production of teaching materials should first start with the identification of possibly already existing OER. Nevertheless, searching for such resources might be a time-consuming process. Furthermore, even if such resources exist, they may use different conventions and notations that may be confusing to the students. Designing one’s own teaching resources might be, in some cases, a more teacher time- and student learning-efficient investment.

Another aspect to consider when developing OER is how to make such resources easily accessible and known to others. Obviously, the resources can be shared on the EEDA platform among the different teachers present on the platform. This represents a large pool of persons

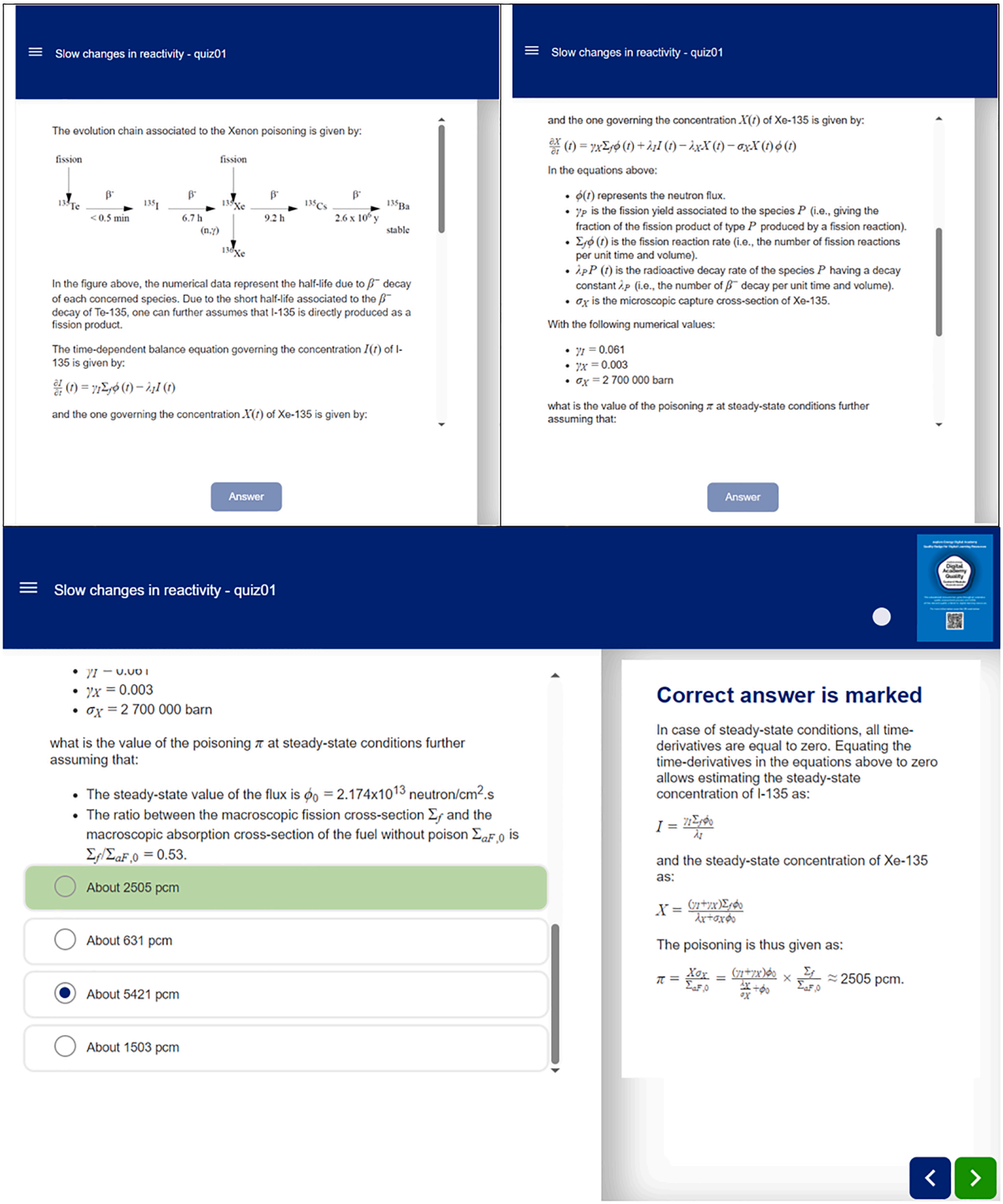

Fig. 8. Example of a quiz (the top figures give the problem statement, and the bottom figure presents the different alternatives). In the screenshot above, the student chose the third alternative, which was incorrect. The correct answer (highlighted in green) with additional explanations were then given to the student. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

who have access to the resources and may decide to re-use them or parts of them in their own teaching, thus reaching many other students. Reaching students not aware of the EEDA platform might be more difficult though. This might even represent a serious showstopper to the objective of making the course open to all. In the present case, the resources were also advertised using first LinkedIn. LinkedIn offers the possibility to write "articles" on one's personal page and those articles are permanently visible at the top of the author page. Writing a short article and referring to it in a LinkedIn post easily allows spreading the information about the course modules. The course modules will be soon advertised on the OECD/NEA Educational Resource Hub currently under development at the OECD/NEA.

The LMS also comes with a review platform to be used both by the author of the learning resources and by external reviewers of those resources. The review aims at identifying whether the modules follow some basic principles in terms of course design, pedagogical principles, quality of the learning resources, etc. A positive self-evaluation results in the automatic issuance of a certificate of quality. Likewise, a positive external review results in the automatic issuance of an additional certificate.

As of today, the only point of the LMS that would need to be improved is the possibility for the teachers to get access to learning analytics data, i.e., data about how the students use the resources, how engaged the students are, how they perform on the various tasks, and the possible discussion threads/comments they initiate on the LMS. For the time being, only the LMS developers have access to those data.

5. Conclusions

Three course modules giving an "introduction to nuclear engineering" to people having an engineering background were developed. Following the OER principles, the modules are freely accessible, and their contents can be re-shared. Great efforts were devoted to preparing highly structured high-quality contents. Since the resources are used in self-service, the chosen structure helps the student progress through the different chapters of the modules while guaranteeing learning. Auto-graded activities with feedback also provides means for the students to self-assess their learning.

Even if the resources were developed with a very low budget, a high pedagogical quality of the entire course was achieved through careful planning, development, and implementation of the resources. As some of the students mentioned after completing the modules: "Thank you very much for this amazing opportunity!", for which the teacher is particularly thankful.

Some work was initiated to offer the modules in the OpenEdX format (following the EEDA concept earlier presented), thus allowing reaching a wider audience and providing to the teacher learning analytics capabilities.

Finally, other teachers are invited to join this OER initiative by contacting the authors of this paper and by proposing additional resources to the ones already existing on the platform. A widening of the scope of the already proposed modules to, e.g., nuclear medicine and nuclear law, might also be considered.

With the deployment of new reactors in emerging countries and the renewal of the existing fleet, it is expected that the needs in education and training in nuclear science and engineering will be massive in the future. Being able to offer training possibilities available on-demand and in a flexible manner is likely to become highly sought-after. Modules as the ones presented in this paper could be used either as a means to provide an orientation in the field or, by complementing those with synchronous activities lead by teachers, as a more in-depth training in selected key areas.

CRediT authorship contribution statement

C. Demazière: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **T. Fransson:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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