Horizon 2020
European Union funding
for Research & Innovation

ESFR-SMART

Research and Innovation Action (RIA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 754501.

Start date : 2017-09-01 Duration : 48 Months
http://esfr-smart-h2020.eu

New pedagogical approach to teaching about Generation-IV fast reactors

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ESFR-SMART - Contract Number: 754501

Project officer: Roger Garbil

Document title	New pedagogical approach to teaching about Generation-IV fast reactors
Author(s)	Pr. Christophe DEMAZIERE, Diana CUERVO (UPM), Eugene SHWAGERAUS (UCAM)
Number of pages	22
Document type	Deliverable
Work Package	WP11
Document number	D11.1
Issued by	Chalmers
Date of completion	2019-06-14 14:52:29
Dissemination level	Public

Summary

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Approval

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2019-09-18 14:38:50	Dr. Konstantin MIKITYUK (PSI)

European Commission | Horizon 2020 European Union funding for Research & Innovation

ESFR-SMART
sodium fast reactor safety

Action	Research and Innovation Action NFRP-2016-2017-1
Grant Agreement #	754501
Project name	European Sodium Fast Reactor Safety Measures Assessment and Research Tools
Project Acronym	ESFR-SMART
Project start date	01.09.2017
Deliverable #	D11.1
Title	New pedagogical approach to teaching about Generation-IV fast reactors
Author(s)	Christophe Demazière (CHALMERS), Diana Cuervo (UPM), Eugene Shwageraus (ECAM)
Version	01
Related WP	WP3.1. Dissemination, education and training
Related Task	T3.1.1. New pedagogical approach to teaching about Generation-IV fast reactors (CHALMERS)
Lead organization	CHALMERS
Submission date	31.08.2019
Dissemination level	PU

This project has received funding from the Euratom research and training programme 2014-2018 under the grant agreement n°754501

History

Date	Submitted by	Reviewed by	Version (Notes)
28.02.2018	C. Demazière (CHALMERS)		Preparation of a report structure (version 01)
15.10.2018	C. Demazière (CHALMERS)		First draft of the report (version 02)
27.02.2019	D. Cuervo (UPM)		Update of Sections 2 and 4 with CDIO (version 03)
08.06.2019	E. Shwageraus (ECAM)		Writing of Section 5 (version 04)
14.06.2019	C. Demazière (CHALMERS)		Finalization of the report (version 05)

Summary

This report gives an account of new pedagogical approaches being introduced in tertiary engineering education and aimed at improving student learning. Such methods are often subsumed under the term of *active learning* methods, based on the observation that students learn much better if they are engaged in well-designed activities under the teacher's supervision. In most cases, active learning methods heavily rely on the use of digital technologies to support learning and even to complement the synchronous interactive sessions with asynchronous sessions. In this report, some examples of active learning methods are presented, as well as some examples of digital technologies to support or complement learning. Some illustrations of the use of such new pedagogical approaches in nuclear engineering are given. How to use active learning methods in existing curricula is also discussed. A more widespread use of active learning methods and digital tools in nuclear engineering would allow making the field more attractive, pedagogy-wise, as well as better educating tomorrow's nuclear engineers.

1. Introduction

The area of engineering education and tertiary education in general have been exposed to major changes in recent years, where student-centred pedagogical approaches aiming at putting student learning as the primary focus have been introduced. Beyond the technical knowledge the students acquire, the way the students learn plays a very important role. Research in engineering education and in pedagogy clearly demonstrates that students learn much more efficiently when they are actively involved in teaching activities under the supervision of the teacher. "Learning by doing" is a pillar of a deeper approach to learning. By better acquiring both conceptual and procedural skills, this form of teaching method has the advantage of educating tomorrow's engineers much better prepared than other more classical forms of teaching.

In this report, the use of student-centred pedagogical approaches is described mostly from a practitioner's perspective, with emphasis on engineering education. The use of active learning method favouring deep learning is analysed, together with how digital technologies can support active learning. Examples of active learning strategies, both combined with digital technologies and not, are reported. Finally, how active learning could be used to improve teaching in existing nuclear engineering curricula is considered.

2. Active learning tools and methods

a. Definition of active learning

Learning can be considered as a process, which the students need to go through. One paradigm often used to define the various learning steps is Bloom's revised taxonomy of the cognitive domain [1]. This process, illustrated in Fig. 1, is defined as a sequence of various skills, starting from lower-order thinking skills to higher-order thinking skills. In the lower order thinking skills, students try to remember and understand the course concepts they were presented. In the higher-order thinking skills, students try to utilize such concepts on their own. Those skills include applying, analysing, evaluating the course concepts and creating. What the various skills represents and contains is more precisely exemplified in Fig. 1.

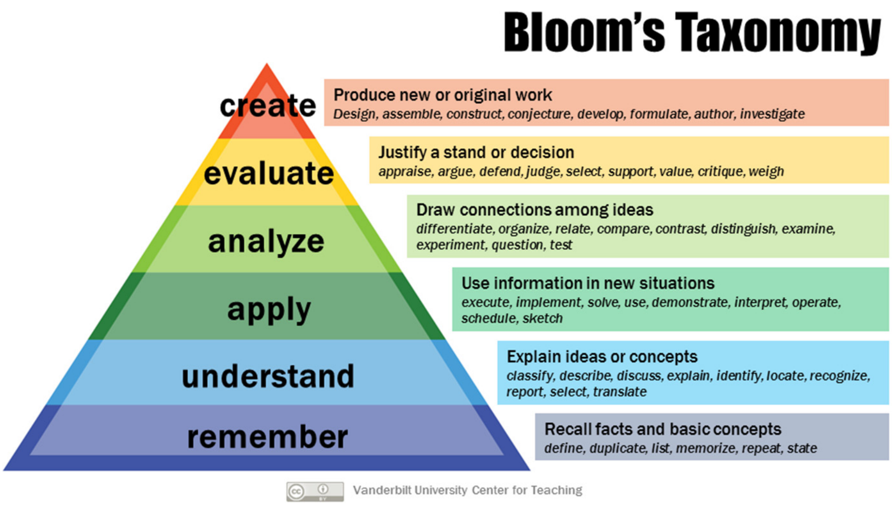

Fig. 1 – Illustration of Bloom's revised taxonomy for the cognitive domain, with higher-order thinking skills at the top of the diagram (from [2]).

Teachers should strive to reach in their teaching set-up as high as possible thinking skills among students. Higher-order thinking skills are triggered when students are given the possibility to utilize the concepts they were introduced to. This requires from the teachers designing some engaging activities in which the students are actively involved. This is often referred to as *active learning*. The main incentive is the fact that one learns much better by doing and experiencing oneself, a principle called in everyday' s jargon "learning by doing". Practice is the essence in reaching higher-order thinking skills in Bloom's revised taxonomy.

Many definitions of active learning exist. The one generally accepted is given in [3] as follows: "Active learning is anything course-related that students in a class session are called on to do other than simply watching and listening to a lecture and taking notes."

The backbone of active learning is to put student learning as the primary focus of the pedagogical approach used. A student-centered approach is thus required.

b. Advantages and disadvantages of active learning methods

The main advantage of active learning methods lies with the fact that students learn much better in such a pedagogical set-up. Their learning process goes beyond the lower order thinking skills in Bloom's revised taxonomy of the cognitive domain, as compared to not involving any active learning element. Many studies demonstrate that the learning outcomes are greatly superior when including active learning [4]. Another indirect advantage of active learning can be perceived as an attractive way of teaching to both the students and the teachers. For the students, a pedagogical approach favouring their learning is obviously an approach of definite benefits. If asked, the students would choose a course where the pedagogical approach improves their learning, as compared to an approach not favouring it. In addition, by putting student learning in the centre of the pedagogy, the teachers are seen as persons caring for their students, a social aspect of importance for establishing a climate favourable to learning. For the teachers, active learning has also a rewarding dimension, since it is through the engaging learning activities that interactions between the teachers and the learners occur. In other words, it is via such activities that the teachers can more efficiently help the students in their learning.

Although very attractive per se, some disadvantages and foreseen difficulties might also be associated to active learning. Since most students were exposed in their education to passive learning, i.e. in-class sessions during which information/knowledge is given to them by the teachers ("sage on the stage"), they are not used to being put in the centre of the pedagogical approach, where they need to engage in learning activities, with help from the teachers ("guide on the side"). In addition, the students become responsible for their learning, as well as for their success or failure to perform well. It is thus essential that the learning activities are designed in such a way that students feel that (a) they can work in a relaxed atmosphere without any fear to answer incorrectly/underperform, and (b) they can get help from their peers and from the teachers. Designing such active learning elements is also perceived by the teachers as challenging for several reasons. First, active learning sessions require careful planning to be efficient. What active learning activities should be used for often depends on the topics being presented and their design is far from trivial. Second, the teachers themselves are not used to such a teaching paradigm, which put them outside of their comfort zone. Because of their relative inexperience in this area, simply finding engaging activities with the students might be the biggest obstacle from a teacher's perspective.

c. Examples of active learning methods

Since embedding active learning elements in one's teaching is often considered as difficult by the teachers, some examples of activities that can be used in class are presented.

The structure and formats of the activities can often be categorized as follows [3]:

- Individual activities. Each student is asked to carry out the required activity on its own in a given time-period, after which a wrap-up is organized by the teacher. During this wrap-up, the teachers might ask some students to share with the class the results of their activity.

- Small group activities. Small groups of students are formed, and they are asked to carry out the required activity collectively in a given time-period. Depending on the size of the groups, extrovert students might nevertheless be the ones driving the activity, at the expense of the more introvert students. Like for individual activities, a wrap-up discussion is led by the teacher, where a few selected groups share their results.
- Think-pair-share activities. Each student is first asked to carry out the required activity on its own. Thereafter, students are paired. Each student has then to discuss with his/her peer the activity, before a wrap-up is organized by the teacher, possibly asking a few pairs to share their results. In this set-up, the students can learn from each other. Compared to small group activities, personal opinions emerge more easily, with less influence from possible imbalance between extrovert and introvert personalities.

Beyond the structure and format of activities highlighted above, different active learning methods can be implemented. A non-exhaustive list of examples is given below [3]-[9]:

- *Applications/examples/demonstrations*. A course concept is chosen by the teacher, who then demonstrates it via a practical example. This could for instance be a laboratory experiment illustrating this concept. This technique, although time-consuming, allows catching student attention. More in-depth discussion/activities building upon this demonstration are then made easier, especially if the students can themselves participate to the demonstration.
- *Sequence of questions/chunked problem analysis*. A rather complex problem is chosen by the teacher and split into several simpler problems. The students are guided through the solution procedure with help from the teacher. The first smaller problems should be made sufficiently easy so as to build student self-confidence. While progressing trough the entire problem, more advanced questions are tackled/solved.
- *Student-generated content*. In this active learning technique, students are asked to find learning materials by themselves, create contents accordingly, present those to others, from whom they also get feedback. Using the resources that they have access to, and most notably electronic resources, internet inclusive, students first gather learning materials on a topic given to them by the teacher. From those materials, the students extract the relevant information, that they summarize in the form of e.g. a short presentation. Other supports could be used: videos, wikis, webpages, etc. This generated content is thereafter shared with other students. Finally, the students comment on each other's work and provide constructive feedback. The teacher monitors the process and intervenes either for correcting possible misconceptions or to provide additional information and feedback.
- *Experiential learning*. The students are immersed into learning experiences. A classical example is a laboratory exercise, where the students have to apply, via hands-on activities, the concepts that they earlier learned. Such laboratory exercises could also be based on computer-assisted exercises, in which the students have to play with e.g. a graphical user interface earlier developed and aimed at demonstrating some particular concept. Although not always easily applicable in engineering education, another very efficient form of experiential learning is role play.
- *Discussions*. A course concept is chosen by the teacher. The students are then asked to discuss together in pairs or small groups this concept or some related questions posed by the teacher. The purpose of the discussions is to make peer-to-peer exchanges possible and to make the students reflect on the discussed subject, thus favouring a deeper learning of that subject.
- *Classroom Assessment Techniques (CATs)*. Two main CATs are typically considered: minute papers and concept maps. In the *minute paper* technique, a question is formulated by the teacher usually at the end of a teaching session, based upon the concepts earlier presented in that session. The students are then asked to reflect, either individually or in groups, on the question. Thereafter, the students are required to write down, either individually or collectively, their answer and associated reasoning in very few sentences. After the session, the teacher can review the answers and assess whether the presented concept was properly understood. If not, some clarification could be made at the next teaching session. In the *concept map* technique, students are asked to extract from some pre-determined materials the salient concepts present in those materials. Thereafter, the students should establish the links existing between those concepts. This technique is particularly efficient in helping the

students to build a conceptual understanding of a course, at organizing the possible hierarchical structure and links between those concepts, and at thinking about a course in a holistic manner. All of these elements contribute to higher-order thinking skills. Very much focus in engineering education is typically put on procedural understanding and very little focus on conceptual understanding. The use of concept maps thus allows compensating for this unbalance. It should be mentioned that minute papers and concept maps represent active learning elements easily scalable in case of large classes.

- *Quizzes*. In-class quizzes can be used to easily bring some active elements in the classroom. Traditional quizzes using pen and paper could be embedded in the classroom session, or more interactive quizzes could be utilized, in which the students have to answer the quizzes using their laptop, tablet, smart phone, or “clickers”. In the case of interactive quizzes, the teacher has the possibility to directly see, using an adequate interface, how the students answer the quizzes. Depending on the success rates at those quizzes, the teacher can either decide to proceed to the next part of the session (in case of high success rates) or to further clarify a concept (in case of low success rates). The design of good and efficient quiz questions is far from trivial: the questions should rather test the conceptual understanding among students than their ability to simply remember earlier presented concepts.
- *Collaborative learning*. Three forms of collaborative learning are typically encountered: group problem solving, peer-instruction, and peer-feedback. In *group problem solving*, the students are put in groups and they are assigned a task, question, or problem to solve together. Although group problem solving primarily focus on testing student procedural understanding, the necessary collaboration between students force them to clarify the concepts to each other, in order to solve the given problem. This thus improves the student conceptual understanding. In the *peer-instruction* technique, originally proposed by Eric Mazur [6] and illustrated in Fig. 2, the teacher, after careful planning of his/her teaching session, gives a short lecture and a chosen question or concept test. The students are then asked to answer the concept test individually using ideally their laptop, tablet, smart phone, or “clickers”. The teacher then reviews the provided answers. If most of the answers are correct, the teacher can simply explain the correct answer. If a significant fraction of the answers is incorrect, the students are asked to discuss with their peer the question, after which they are asked to vote again. During the peer-discussion phase, the teacher and possible teaching assistants have the possibility to go through the class and discuss with the students their answers and reasoning. The fact that the students have to explain to each other their reasoning help them better understand the course concepts, thus leading to deeper learning. In the *peer-feedback* technique, students are given a task/assignment by the teacher, that they have to complete. The tasks/assignments can be of various forms. They are also given assessment criteria, according to which they will assess the tasks/assignments completed by their peers. These assessment criteria need to be as detailed as possible. The grading process should be split in various elements. Such elements should be as specific as possible, such as e.g. depth of analysis, grasp of course materials, strength of thesis/argument, evidence, conclusion, organization, style, clarity, etc. [5]. For each of those elements, clear evaluation criteria should be provided. Quantitative and qualitative feedback on the tasks/assignments is then provided in class between peers or groups of peers. Participating to the assessment of peers constitutes an additional learning element. Every step in the entire process (performing the task/assignment, assessing it, and providing feedback on it) thus represents a learning opportunity.

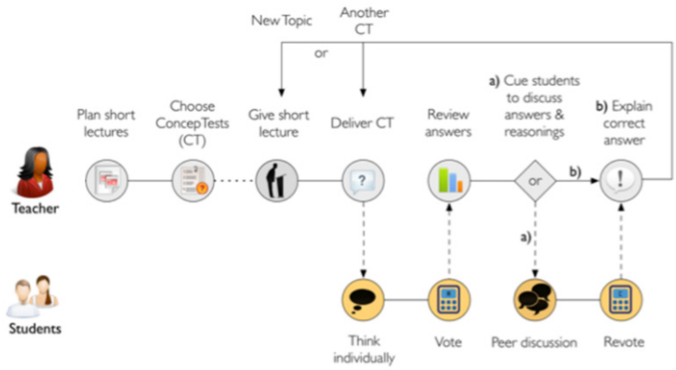

Fig. 2 – Illustration of the peer-instruction technique (figure derived from [7]).

- *Tutorials/packet of problems*. The students are asked to solve, preferably in small groups, some given problems in class with the support of the teacher. When needed, the teacher might lead the students in trying to solve the problems. The teacher can also provide individual support to each of the groups, and depending on their progression, discuss additional topics related to the problem being solved with those groups and challenge the solution procedure by the groups.
- *Hands-out with gaps*. The students are given some hands-out corresponding to the concept being presented by the teachers. At some occurrences in the hands-out, some questions/simple problems are given. Some blank space in the hands-out is provided so that the students can answer those questions or solve the problems while being in class. If possible, the students work in groups for finding the answers/solve the problems.
- *Thinking-aloud pair problem solving (TAPPS)*. The students are paired and given some small task/assignment. One of the two students then explains the step-by-step procedure to solve the given task/assignment. The other student questions his peer in case anything is unclear and can, if needed, provide hints. For the next task/assignment, the roles are reversed.
- *Jigsaw*. A problem is split in smaller ones. Groups of students are formed and assigned to each of the smaller problems. Each group is then asked to solve and discuss its respective problem. Thereafter, new groups are formed. Each new group contains one member of the former groups. Within each group, each student should present to the remaining of the group how they solve the assigned problems. The teacher wraps up the session by summarizing the main points of the different problems and clarifies any issue that might remain.
- *Conceive Design Implement Operate (CDIO)* – The students are grouped together depending on the scope of the problem to be solved. A goal to be achieved by the students is established, such as developing a system/vehicle/software/methodology or any other type of tool that must be conceived by the students in a given context. Based on the knowledge acquired by the students along previous courses and some materials or classes given by the teachers as preparatory work, the students propose the system, design and develop it in order to obtain a solution to the original problem. Usually, a final presentation is given by the students, during which they try to demonstrate that the developed system can achieve the goals originally set.

3. Using digital technology in tertiary education

a. Digital technologies to promote learning

The incentive in the use of digital technologies is to promote learning. Although some of those technologies might appear as very “fancy” and attractive to students at first glance, it is essential that the digital tools contribute to and improve learning. The use of the digital tools, the corresponding learning elements, and how they are implemented in the course structure should always be related to Bloom’s revised taxonomy for the cognitive domain. It is also essential to make sure the sequential implementation of various techniques contribute to gradually reaching higher-order thinking skills in the taxonomy.

When using digital technologies, several other aspects also need to be taken into consideration [3]:

- *Making a variety of learning resources available*. Additional learning resources can be provided to the students in digital form, such as videos, audios, animations, as well as more classical teaching materials (slides, presentations, books and e-books, etc.). The students might also be asked to search for additional resources on their own. While providing these additional resources, it is essential that the teacher checks in advance that the teaching resources are fully consistent with the course, its curriculum, the concepts being presented, the approximations or framework used, the notations used by the teacher, etc. Since the goal of providing a variety of resources is to improve learning, any inconsistency between the materials presented by the teacher and those additional resources might be confusing for the students, thus having a counter-productive effect.
- *Facilitating active student engagement*. Digital tools promoting more engagement, both in in-class activities or in out-of-class activities, could be used. For the in-class activities, one could e.g. rely on on-line quizzes, that the students have to answer using e.g. their laptop, tablet, smart-phone, or “clickers”. Using an adequate web-based interface, the teacher could instantly monitor student understanding and provide feedback accordingly. On-line quizzes can also be used prior to the in-class sessions. On-line quizzes prior to the in-class sessions can be efficiently used in a Just-in-Time-Teaching (JiTT) framework, presented in Section 3.b. Another form of digital tool promoting student engagement could be based on computer-assisted demonstration or exercise or interactive multimedia tutorials, that the students could train on at their own pace as out-of-class activity.
- *Enhancing student-faculty and student-student interactions*. Digital tools such as Learning Management Systems (LMS), e-mails, chat, discussion fora, on-line communication/video conferencing systems (see Section 3.b) allow increasing the availability of the teachers to answer student questions or issues outside of the planned in-class sessions. Such tools also allow students to more easily communicate with each other outside of the in-class session times or ordinary working hours.
- *Providing formative and summative feedback to the students*. In addition to provide feedback to the students when they complete given tasks used for grading them, a much better way to influence student learning and motivate them is to continuously provide feedback to them while they learn. The first form of feedback is referred to as summative feedback (i.e. evaluating student learning) whereas the latter form is referred to as formative feedback (i.e. monitoring student learning). One way to provide formative feedback is e.g. via the use of on-line quizzes. Depending on the answers chosen by the students to the quiz questions, some on-line quizzes tools allow to provide immediate feedback to the students on their learning. In case of incorrect answers, they could also be given some help on how to find the correct alternatives. If such features are not available in the on-line quiz tool and if the class is not too large, the teacher could review the answer to the quizzes and provide feedback.
- *Providing adaptive, individualized, self-paced instruction*. Since students learn differently, the pace at which they can process some new materials might vary significantly from one student to the other. By providing flexible teaching materials that the students could consult e.g. at home at their own pace, learning can be more efficient. One classical example is to use short pre-recorded videos explaining a course concept. The students can follow such videos when they want, i.e. at times when they are most receptive, and can re-wind them if some concept was not clear at first glance. Such flexible learning approaches are also very well suited to students having cognitive disorders, such as dyslexia or autism.

b. Examples of digital technologies that can be used to promote learning

In this Section, some examples of digital technologies that could promote learning are listed. Some of them were briefly mentioned earlier in this document.

In *Massive Open Online Courses* (MOOCs), a very large number of students (typically more than several tens of thousands) are enrolled in virtual classes entirely given on the web and for free. A fee might be asked if the students want to get a course certificate after completing the course. MOOCs are aimed at providing mass education in selected topics. This is achieved by making all the electronic resources available solely on the web, using a web-based platform. The most popular platforms are Coursera, EdX, Udacity and Moodle [10]-[13]. The teaching materials can be made of recorded lectures/videos, reading assignments, on-line quizzes, discussion fora, and assignments. Although some of these materials embed some formative feedback features, there is no possibility for the teacher staff involved in a MOOC to provide individual support to the students. In some cases, though, a number of teaching assistants could e.g. monitor the discussion fora and intervene if/when necessary.

In *flipped classrooms*, the contents usually deliver in class by the teacher in form of lectures is instead made available to the students prior to the in-class sessions, typically using pre-recorded lectures or videos. Since learning is a process that can be described using e.g. Bloom's revised taxonomy of the cognitive domain (see Fig. 1) and that always start with the low-order thinking skills, the advantage of flipping the classroom is to move the one-way delivery of new contents from the teacher to the students outside of the classroom. This makes the in-class time available to more engaging activities, that should be based on some active learning elements aimed at promoting high-order thinking skills, as illustrated in Fig. 3. In the traditional model instead, most of the in-class time is spent on low-order thinking skills, with very little time left to help the students apply, analyse, evaluate the concepts and even create new contents. There are several advantages with the flipped model. Since the delivery of new contents is not taking place any longer in the classroom in a very passive manner as would occur in the traditional model, the students can learn those concepts at their own pace in a much more efficient manner. In addition, in the traditional model in which the students inherently become passive, cannot learn the new content presented to them in the classroom and need to re-digest the content on their own at home, the flipped model allows the students to much more efficiently use their time since they learn this new content only once, i.e. at home. It should nevertheless be emphasized that the flipped model can only lead to higher learning outcomes if the teacher has developed a clear strategy for embedding active learning elements in the in-class sessions.

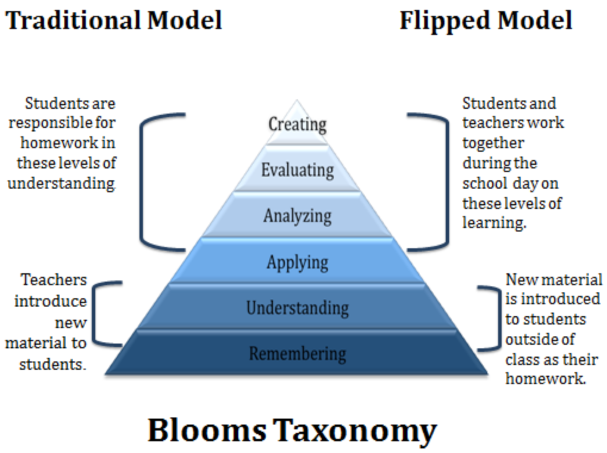

Fig. 3 – The traditional and flipped classroom models in relation to Bloom's taxonomy [14].

In *distant/on-line education*, the education provided to the students is only delivered to the students in a remote manner, typically using web-based techniques, although some more traditional video-conferencing systems can be used for such a purpose. Strictly speaking, this type of education does not necessarily include active learning elements and is often made as one-way communication channels: the teacher delivering new course contents in form of lectures using the video-conferencing system, and the students thereafter completing some assignments to be returned to the teacher. In this format, the teaching can be merely considered as a traditional teaching model applied to a distant audience.

In *Virtual Learning Environments (VLEs)* on the other hand, learning mostly occurs on the web, using a variety of digital resources, developed for improving student learning. In such environments, interactions between the students and the teacher are possible, either in an asynchronous fashion or in a synchronous fashion. Live lectures can also be delivered through VLEs. Typically, a VLE includes an LMS, itself made of electronic resources made available to the students (webcasts/videos, book in electronic format or e-book), on-line quizzes, discussion fora and chats. These tools are further detailed below. VLEs are particularly well suited for distant/on-line education and have the advantage of typically including active learning elements.

Blended learning is a generic term that refers to some face-to-face interactions between the teacher and the students, combined with some learning components delivered through the web. The flipped classroom model is a classic example of blended learning. Nevertheless, any teaching format that includes in-class sessions with web-based out-of-class activities can be categorized as blended learning. Although the essence of blended learning is to improve learning, blended learning does not necessarily include active learning elements.

A *Learning Management System (LMS)* is a web-based platform gathering all electronic resources and digital tools made available to the students. The incentive with an LMS is to give the students a single entry point to all those resources and tools and to guarantee their 24/7 availability. An LMS typically includes the electronic resources made available to the students (webcasts/videos, book in electronic format or e-book), on-line quizzes, discussion fora and chats.

In *Just-in-Time Teaching (JiTT)*, the teacher monitors student learning before they come to class. This technique relies on developing teaching elements that the students have to use before the in-class sessions. The monitoring is typically done using on-line quizzes, as illustrated in Fig. 4, although the teacher can gather other information streams about student learning such as feedback questionnaires on the teaching elements or simply the questions the teacher might have received from the students (via e-mail, discussion fora, or chats) while they were getting prepared to the in-class sessions. Based on this information, the teacher can identify the concepts that were not properly understood. While preparing the following in-class session, the teacher can address the questions raised and tune his/her session to the students' needs.

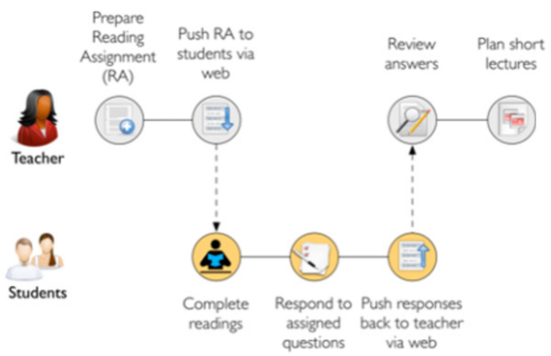

Fig. 4 – Illustration of the JiTT approach relying on on-line quizzes (figure derived from [7]).

In *on-line quizzes*, the students have to answer questions made available on the web using typically an LMS. The quizzes could test both procedural and conceptual understanding. The design of quizzes in the second case is nevertheless more challenging, since quizzes should focus on high-order thinking skills beyond only concept recollection. Depending on the LMS used, the level of sophistication of the on-line quizzes can vary a lot, going from one single answer to be chosen among several ones, or several answers being possible, to graphical quizzes where the students have to select a part of the figure corresponding to the correct answer or where the students have to position several proposed alternatives in a given order. Although the answers to the quizzes might be monitored by the teacher, e.g. when using a JiTT approach, it is essential that the quizzes are not used for grading the students. The quizzes should rather be made available to the students for them to train. In this respect, allowing the students to have several attempts on each quiz is desirable. If the LMS permits it, some help/guidance might be provided to the students when they incorrectly answer a quiz, so that they can understand their mistakes and hopefully converge to the right solution.

Asynchronous/synchronous interactions between the teacher and the students should be made possible during the entire duration of the course. Synchronous interactions refer to instantaneous interactions between the students and the teacher, where asynchronous interactions refer to interactions for which a delay exists between when a question is raised by either the students or the teacher and when this question is answered by either the teacher or the students, respectively. Synchronous interactions are mostly taking place during the in-class sessions, that might occur in the classroom or on the web in the case of distant/on-line education. On the other hand, asynchronous interactions are mostly taking place through the web. Typical examples of asynchronous interaction channels include e-mails, discussion fora, chats, etc. even if the time between when a question is raised and when it is answered can be very short.

Webcasts/videos are typically pre-recorded materials made available to the students, either during the in-class sessions or as out-of-class activities. Such webcasts/videos are particularly well adapted to flipped classrooms as a means to replace the traditional in-class lectures and thus represent preparatory materials the students have to get acquainted with before coming to class. The webcasts/videos could either be the recording of in-class teaching sessions given during a previous course occurrence or made of more advanced and professional recordings showing slides, animations, annotations, and a video of the teacher. In order to avoid possible student passivity while watching the webcasts/videos, such webcasts/videos should be of short duration (typically shorter than 10 min) and should be vivid and "entertaining" as much as possible. Embedding in such webcasts/videos other digital active learning elements also enhances the learning experience. Although it is possible to use webcasts/videos already available on the internet, care has to be taken with the consistency of such other materials with the overall course, particularly with respect to the methods, concepts and notations used.

Interactive multimedia tutorials are web-based animations or exercises, in which the students have to choose between different alternatives in a tutorial, by typically clicking on buttons, setting parameters, etc. The choice then made might influence how to proceed in the next steps of the tutorial. These tutorials are particularly efficient for letting the students train on given concepts and lead to much deeper learning. Such tutorials are typically given as out-of-class activities. In order to be successful, it is thus essential that the tutorials are delivered with a set of clear instructions about how to use the tutorial. An example of a computer-based training exercise developed at Chalmers University of Technology is given in Fig. 5. In this figure, the students can play with the dependence of the reactor period on the reactivity and prompt neutron lifetime. By playing with the reactivity and prompt neutron lifetime, while following some given instructions provided together with this training exercise, the students can better understand why the reactor period varies significantly depending on whether the reactivity is positive or negative, and in the case of positive reactivity depending on the value of the reactivity with respect to the fraction of delayed neutrons.

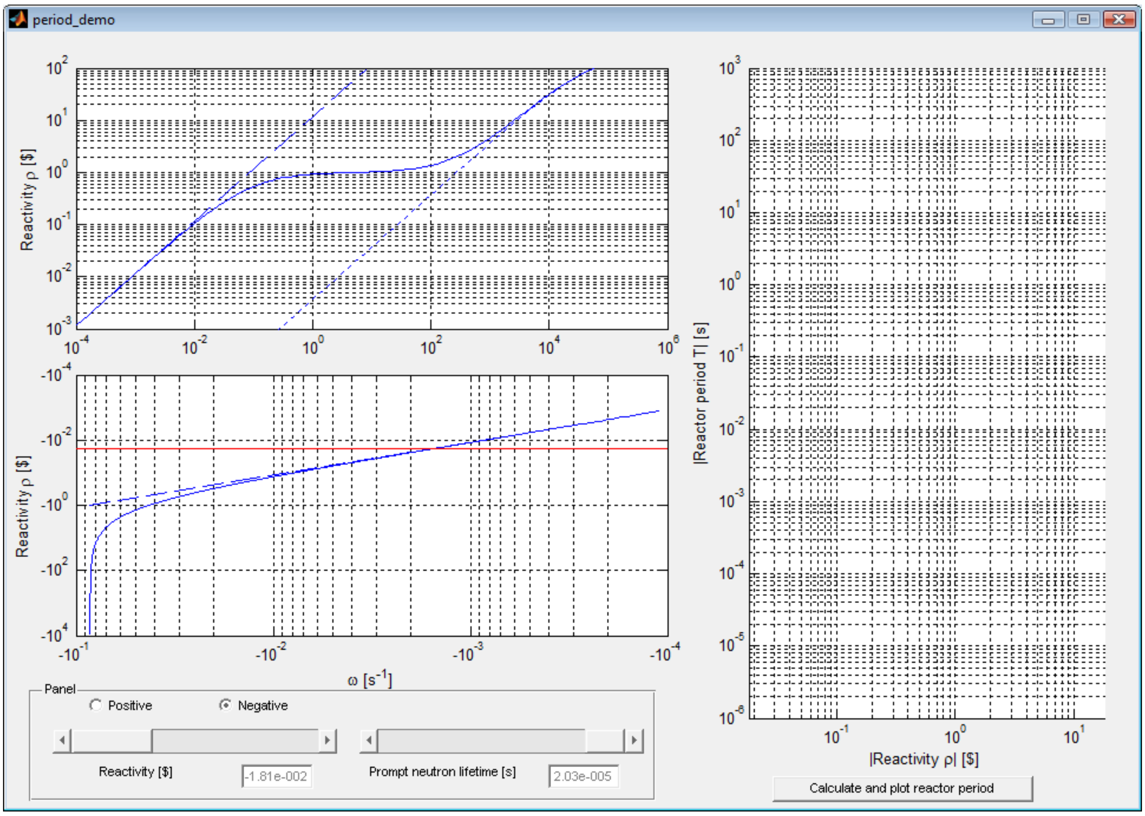

Fig. 5 – Example of a computer-assisted exercise illustrated the dependence of the reactor period on reactivity and prompt neutron lifetime.

Simulations and virtual laboratories are in essence identical to interactive multimedia tutorials. The main difference lies with the fact that typically the former is given in the classroom under the teacher's leadership and guidance, whereas the latter is provided as an out-of-class activity that the students have to train on their own. An example of a virtual laboratory is shown in Fig. 6. This figure illustrates a Matlab-based graphical user interface plotting the spatial distribution of the neutron flux in a 2-group 2-region reactor model and developed at Chalmers University of Technology. The students have the possibility to change some of the parameters used in the model, in order to appreciate their effect on the spatial distribution of the neutron flux. The calculations are performed in the background without any need for the students to intervene.

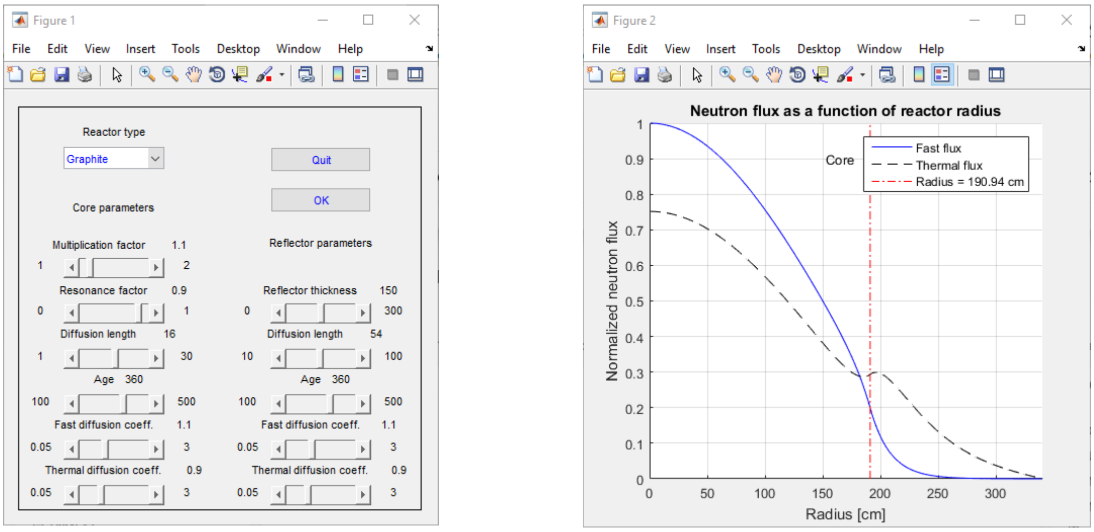

Fig. 6 – Example of a graphical user interface illustrated the spatial distribution of the neutron flux (right figure) depending on some input parameters (left figure).

Discussion fora are conversation threads that can occur either on an LMS, chats, or other means of communications. Discussion fora might either include all students in a class or be limited to a group of students, if need be, as for instance in the case of group work. The smaller the groups are, the easier the students tend to actively contribute to the discussion fora. When the discussion forum is open to an entire large class, the students might be reluctant in posting their first message. In order to circumvent this virtual shyness, it is recommended that the teacher initiates the discussion by putting a few first messages, on which he/she expects the students to react, comment, etc. The main advantage of discussion fora as compared to group e-mails is that a hierarchical structure can be built in the discussion topics and that all previous messages, questions, and replies are visible and easily accessible at all times. Discussion fora are particularly well suited for having the students discussing group assignments and home assignments. Finally, the teacher can monitor such discussion fora and intervene/provide guidance if need be.

Social networks, like Facebook and Twitter, constitute a communication channel well appreciated by students that allow them to easily share contents available on the web. In addition, students can comment the contents they share. In essence, social networks could be compared to discussion fora. They never differ in two main aspects: (a) the content is much less structured than on a discussion forum, but (b) they much more easily permit the sharing on multimedia elements (videos, animations, sound). Social networks could for instance be used in project assignments for which the students have to find relevant sources of information on their own.

4. Examples of active learning-based courses in nuclear engineering using digital technologies

In this section, a few examples of courses in nuclear engineering making use of active learning and digital techniques are given. The list given hereafter is not by any means exhaustive.

a. Flipped classroom

A few initiatives attempting to use flipped classrooms in nuclear engineering exist.

At Chalmers University of Technology (Sweden), a course in the physics of nuclear reactors has been given in a flipped model since the academic year 2015/2016. The course was earlier developed in a classical teaching set-up, made of traditional lectures and tutorials and given in this format from the academic year 2009/2010 until the academic year 2014/2015. The course development was based on the rationale of presenting the physics of nuclear reactors in an integrated viewpoint [15]. Instead of teaching neutron transport, fluid dynamics, and heat transfer separately, the design of the courses was made aiming at teaching all subjects in a self-contained course. The aims of course are for the students to be able to derive the governing equations of the physical processes involved and to derive analytical solutions for simple enough configurations, in order for the students to get physical understanding and insight about the considered physics and results to be expected. Tackling all important physical phenomena guarantees a holistic approach to the area. This is of particular importance in the area of nuclear reactor transients, where the analysts need to be equally knowledgeable in neutron kinetics and thermal-hydraulics.

From a pedagogical viewpoint, the flipped version of the course included pre-recorded lectures available for on-demand viewing; on-line quizzes embedded in the webcasts; the possibility to pose questions to the teachers while watching the lectures; easy and rapid rating of the lectures and the possibility for students to provide more specific feedback on the lectures; and discussion fora.

Because of their pre-recorded nature, the webcasts were specifically designed to mirror the extent of the covered topic. The webcasts were thus of various lengths, following a holistic approach (introduction, presentation of the subject, and conclusion/reminder of the presented concepts). The webcasts were recorded with the teacher's voice (but without any video) and using on-screen annotations, thus making the webcasts vivid.

The on-line quizzes were designed in such a way that thinking skills beyond merely remembering concepts were triggered, including applying, analysing and evaluating concepts, according to Bloom's revised taxonomy for the cognitive domain. The quizzes were carefully designed so that instead of simply asking for memorized information, they required the students to comprehend the key concepts. Moreover, embedding quizzes in the pre-recorded webcasts allowed splitting the lectures (webcasts) into smaller chunks, increasing student attention and thus improving the conditions for learning. As an additional benefit, the on-line quizzes allowed the teachers to continuously monitor the students' comprehension of key concepts.

The pre-recorded webcasts were complemented with the possibility for the students to easily pose questions to the teachers, using a built-in function in the player for the webcasts.

At the end of each pre-recorded webcast, the students could rate, on a voluntary basis, the pre-recorded lecture. By making the rating of the pre-recorded lectures easy and fast, again using a built-in function in the player, most of the students did rate the lectures. The students also had the possibility to provide written comments.

All the collected information – the answers to the quizzes, the questions sent to the teachers, the rating of the pre-recorded webcasts, as well as additional comments provided by the students – was used to prepare wrap-up sessions designed to meet the students' needs at this moment in the course, to be given in the classroom. This approach builds on the concept of JiTT earlier defined in Section 3.b. The wrap-up sessions contained three key parts: 1) providing a brief summary of the key concepts and their relation to the structure of the chapter so that the students could relate the details to the overall picture, thus favouring a more holistic approach to learning; 2) answering the questions that the teachers received; and 3) going through the quizzes in an interactive way, and discussing different alternatives. This last part of the wrap-up sessions is where the degree of interaction between the students and teachers was highest and provided a last opportunity for the teachers to address misconceptions and direct the students onto the right track.

For each of the chapters studied, the learning sequence for the students is thus made up of several parts, as illustrated in Fig. 7. The first ones include studying the lecture notes, watching the webcasts, and completing the quizzes. Interaction with the teachers is only possible in an asynchronous fashion, using e-mails, the webcast built-in function to send questions, or via the webcast feedback sheets. Synchronous interactions become possible during the wrap-up sessions and the tutorials in the classroom. Peer-instruction is also used to increase interactions between the students and to enhance learning. Finally, the students have to apply, analyse, and evaluate the studied concepts while solving the home assignments, thus using the higher-order thinking skills in Bloom's revised taxonomy. The home assignments are carried out in groups.

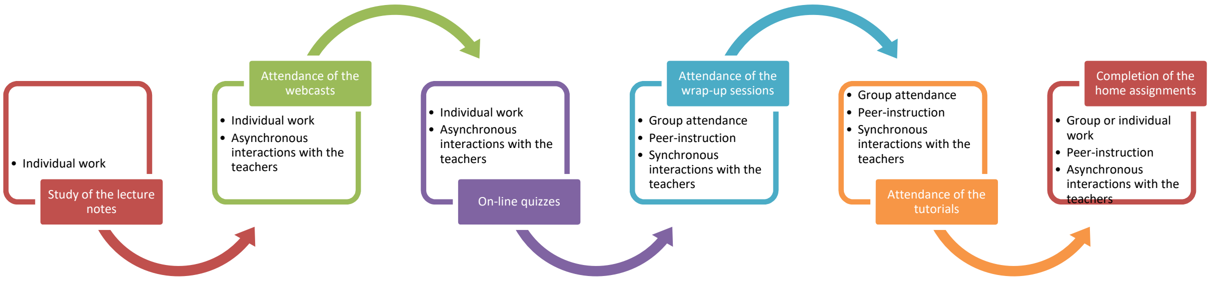

Fig. 7 – Illustration of the learning sequence in the flipped course given at Chalmers University of Technology.

At the University of Ontario (Canada), an undergraduate course in nuclear engineering was partially flipped [16]. A textbook was used and very detailed course notes were posted on a LMS. The students were asked to read given chapters in the textbook according to a given schedule and to study the corresponding course notes. Although planned in the near future, no video recording of lectures was made available to the students before attending the in-class sessions. The in-class sessions started with a quick review of materials that the students had to study, then followed by some time for questions and answers. In-class problems (also used to grade the students) were then assigned to the students. The same problems were actually given to the entire class. Different sets of numerical values and of multiple-choice answers were nevertheless given to each student. Collaboration between the students was allowed, as well as access to all course materials and resources (internet-based ones inclusive). The students could also ask questions to the teacher, preferably out loud.

At the University of Illinois (USA), a course in nuclear engineering was flipped [17]. The lectures made by the teacher and originally delivered in the classroom were instead recorded and made available to the students before attending the in-class sessions. The students were asked to watch the recorded lectures, if possible, in small groups of four to five persons. The synchronous in-class sessions were then devoted to answering questions the students had and at clarifying difficult concepts.

b. Flipped classroom combined with a VLE

The only example, known to the present authors, of a flipped classroom course combined with a VLE is again found at Chalmers University of Technology (Gothenburg). A course in the modelling of nuclear reactors has been given in this format since the academic year 2012/2013. The course was earlier developed in a classical teaching set-up, made of traditional lectures and tutorials and given in this format from the academic year 2009/2010 until the academic year 2011/2012. As for the physics course offered in a flipped classroom set-up and described in Section 4.a, the course follows a holistic approach, tackling the modelling aspects of neutron transport, fluid dynamics and heat transfer [15]. The aims are for the students to be able to comprehend and apply the methodology used by the nuclear community for simulating the behaviour of nuclear reactors. Due to the strongly heterogeneous characteristic features of such systems, analytical solutions do not exist, and instead, computer models need to be used. The main emphasis of the course is to derive the typical algorithms used in such codes, the approximations used, and the corresponding limitations, with the objective that the students can later on use these codes with confidence and for situations falling into the range of validity of the algorithms.

From a pedagogical viewpoint, the same elements as for the physics course described in Section 4.a are present: pre-recorded lectures available for on-demand viewing; on-line quizzes embedded in the webcasts; the possibility to pose questions to the teachers while watching the lectures; easy and rapid rating of the lectures and the possibility for students to provide more specific feedback on the lectures; and discussion fora. The learning sequence is also identical to the one presented in Fig. 7.

The main difference compared to the physics course nevertheless lies with the fact that the course format was combined with a VLE. During the academic years 2012/2013 – 2015/2016, the synchronous sessions were made of live-streamed sessions broadcasted on the internet, for both the students geographically located at the university and the students following the course from other remote locations. In practice, this meant that even the on-site students had to follow the synchronous sessions while seating at home. Since the academic year 2016/2017, an interactive teaching room allowing combining on-site attendees with remote attendees is available at Chalmers University of Technology [18]. This room, for which a picture is given in Fig. 8, is furnished with movable chairs, tables and whiteboards enabling the use of a more student-centred pedagogical approach. In addition, the room is equipped with audio and video hardware and software (2 cameras, 4 ceiling microphones, 6 ceiling loudspeakers, and 1 portable microphone, all combined using an AV Bridge™ Matrix Pro). The core of the system is driven by a high-end tablet PC running Adobe Connect and connected to the Bridge. An additional screen aimed at handling the communication with the remote participants is connected to the tablet and a video projector is mimicking the screen of the tablet. This set-up allows the tablet screen to be shared to the on-site attendees (via the projector) and to the off-site attendees (via Adobe Connect). Because of the nature of the tablet, the teachers have the possibility to show slides, annotate them, and write on the screen, all of this being visible to the on-site and off-site students. Moreover, the audio/video equipment allows synchronous interactions between the on-site and off-site participants in form of digital content sharing, audio interactions, and video communication. The main advantage of the new teaching room is that the on-site students can all sit together during the synchronous sessions, which makes the interactions and discussions between the on-site students easier.

Fig. 8 – Picture of the interactive teaching room developed at Chalmers University of Technology (©Anna Wallin).

It should also be mentioned that a short course on the “Fundamental of reactor kinetics and theory of small space-time dependent fluctuations in nuclear reactors” was given on June 18-21, 2018 at Chalmers University of Technology following the same pedagogical approach, i.e. a flipped model combined with a VLE and offered both to on-site and off-site attendees. This course is part of a series of courses/workshops organized for the Horizon2020 Euratom-funded CORTEX project (CORe monitoring Techniques and EXperimental validation and demonstration) [19].

For the sake of completeness, another example which could partially be categorized as a flipped classroom combined with a VLE is found at the University of Ontario (Canada), where a graduate course is offered exclusively on-line to remote students [16]. The students are asked to get prepared in advance to the synchronous sessions, that are organized by video-conferencing. The students are also assigned tasks during such sessions, on which they can collaborate under the teacher's supervision.

c. MOOC

MOOCs have experienced a very large expansion phase lately, with 2012 being qualified by The New York Times as "The year of the MOOC". It is therefore not surprising that several MOOCs related to nuclear energy are already available or were previously given. A non-exhaustive list is given hereafter.

On the FutureLearn platform, one finds two courses:

- *Understanding nuclear power*. In this course, the role nuclear power might play in the energy future is examined [21].
- *The Science of Nuclear Energy*. In this course, the science of nuclear power is explained and the arguments for and against nuclear power are presented [22].

On EdX, one also finds three courses:

- *Understanding Nuclear Energy*. In the course, the science and technology behind nuclear energy are explained, together with the special features of this energy source [23].
- *Nuclear Reactor Physics Basics*. In this course, the students become familiar with nuclear reactor physics and understand what happens in the nuclear reactor core [24].
- *Nuclear Energy: Science, Systems and Society*. In this course, the students learn how a nuclear reactor works and what the future of nuclear fusion looks like [25]. They students are also presented the numerous useful applications of nuclear radiation.

Finally, on Coursera, one course can be found: *Nuclear Reactor Physics Basics*. In this course, the students are introduced to a range of concepts, ideas and models used in nuclear reactor physics [26]. A course on nuclear science and technology titled "A Look at Nuclear Science and Technology" was previously offered on Coursera but does not seem to be any longer available on the platform.

All courses above are now offered as archived courses, i.e. self-paced courses without any pedagogical support. The only exceptions are the MOOC titled "Nuclear Energy: Science, Systems and Society", to be given in early 2019 and the MOOC titled "Nuclear Reactor Physics Basics", to be given in late 2018.

d. CDIO

The CDIO methodology [9] has been widely used in the Escuela Técnica Superior de Ingenieros Industriales (School of Industrial Engineering) at the Technical University of Madrid (UPM), Madrid, Spain. In the frame of nuclear engineering education, a course named "INGENIA-NUCLEAR Design and simulation of a PWR" is part of the offer given to students for obtaining the "Industrial engineer" MSc degree.

The objective of this course is to make the students familiar with the design of a "simulator" for nuclear reactor analysis. In this way, they translate the scientific knowledge that they have from different courses to a practical and real project. For this, they have to conceive and design the simulator with the help of the teacher who gives them, in the first sessions of the course, an introduction to these types of tools. Although the tool itself is already developed as a software to be used by the students, they have to optimize the tool by means of hypothesis analysis and model selection. This will be the task of a first group of students. Another group will have to generate the database used by the simulator and validate it utilizing real operation data from a reactor. A different group of students has to optimize the operation of the reactor that is being simulated by the use of the simulator. And finally, the fourth group analyses the calculation uncertainties using a methodology explained by the teacher.

The work to be performed by the different teams has to be executed in a collaborative manner, both within each group and between the groups. When the work is complete, several wrap-up sessions are organized, during which the students present the work performed and the results obtained. In these sessions, the implications of the work in terms of sustainability and social responsibility are also analysed.

Also, some of the courses included in the "Nuclear science and technology" MSc degree are given following some of the ideas of a CDIO approach, although restricted to the design of experiments or to methodologies. Particularly, the course "Nuclear thermal-hydraulics" includes a practical approach of the thermal-hydraulic analysis of a given problem. The students (in this case individually) either use different codes, based on different models and hypotheses, for analysing the same thermal-hydraulic problem or use the same code but considering different hypotheses. A comparison of the results gives to the students an idea of the implications of the use of different approaches to solve the same problem not only in terms of results obtained but also of practical issues, like calculation time or definition of the problem.

e. Open on-line courses

Although some open on-line courses in nuclear science and engineering exist, such as:

- The courses in the package *Nuclear Science and Engineering* on the MIT OpenCourseWare [27]
- The courses as part of the *Cooperation in Education in Nuclear Chemistry* (CINCH and CINCH-II European projects) on Moodle [28],

active learning elements were not systematically included in all parts of such courses.

5. Implementation of active learning techniques in existing nuclear engineering curricula

Flipped classroom can benefit a great deal from active learning techniques as evident from the above discussion. However, active learning is also used in traditional teaching although it might be not as efficient in terms of utilisation of teachers face-to-face time with the students. The high value learning in traditional classrooms is often expected to happen during independent coursework assignments done by the students outside the classroom and this is precisely where and when involvement of teaching staff is the most needed. This has been recognised and addressed through a number of channels in various institutions. A number of examples of such activities are summarised below.

- Following each lecture delivered by traditional means (face-to-face in a large auditorium), the students are assigned a set of example problems which they attempt to solve after the lecture alongside a review of the lecture material. Regardless of the success in these attempts, the students then attend small group tutorial sessions where they are expected to be ready to participate in a teacher's guided discussion on the strategies to solve the given problems. The teacher only facilitates the discussion making sure each student in a group participates and eventually understands the discussed material and problem-solving strategy. The format of these tutorial sessions varies across different institutions and courses depending on the nature of the course material. These can be as small as one-to-one (student-teacher) sessions or as large as being in the same forum as the lecture itself. Also, in terms of frequency, these could be regular (e.g. weekly) tutorials or a one-off session to provide feedback on a single significant piece of coursework or a review session in preparation for an exam. The key common feature of these sessions is that the students have already performed some work independently by themselves prior to the tutorial which is what greatly increases the learning outcome.
- Another activity mentioned in previous sections is the use of demonstrations and virtual (computational) labs. A typical format for such activity would be a workshop which demonstrates the basic features and theory of a computer model simulating the behaviour of a complex real system (e.g. the nuclear reactor core or the whole plant). The workshop is then followed by a coursework asking the students to exercise the model for a number of scenarios, observe and document the system's behaviour and, most importantly analyse and interpret these observations. The ability to perform the latter part is the most valuable learning outcome because it allows not just experiencing the behaviour

of a complex real systems in a classroom environment but also being able to critically assess it using the theory introduced in lectures and other learning activities. A typical exercise may ask the students to introduce different types of perturbations into a system at equilibrium and then observe, interrogate and interpret the system's time-dependent response to such perturbations. Or, inversely, a pre-set model may exhibit a certain time-dependent behaviour and the students would be asked to identify the source of the initial perturbation.

- An additional active learning technique widely used in traditional teaching corresponds to various types of assignments performed in groups. The benefit of this type of learning is, again, through independent research on a particular research topic with an opportunity for feedback from peers within each group or from peers in other groups if the assignment output is presented in a large open forum, as well as continuous mentoring and feedback from the teaching staff during the preparation, research output presentation, and marking. Having the student groups to perform their tasks in some form of competition with each other (e.g. defending alternative approaches to solving a certain problem or promoting alternative nuclear technologies – lead-cooled versus sodium-cooled reactors for example) adds to students' enthusiasm and helps the learning process. It also allows each group to study one aspect in reasonable depth, while still being exposed to basic understanding pros and cons of the alternatives if the exercise outcomes are presented to the whole group or even as part of a competitive debate. All group projects or assignments inevitably have their challenges. Tension can arise within groups because of varying enthusiasm of students to contribute to the task, their personalities and temperament. Occasionally, contributions may also vary simply because students on the same course have different schedule and academic load in the period of the group activity. There are no ideal solutions to these problems but a number of ways to manage them and prevent the tension do exist. Firstly, the students should be made aware of these problems up front and offered a set of tools to resolve them should they arise e.g. how to divide responsibilities, manage time and resolve conflicts. Peer evaluation of individual group members could be included in the final exercise mark along with the group mark and individual performance mark by the teaching staff.
- Finally, the use of LMS is widely implemented in many universities to manage electronically all types of course activities. Each course/module would have access-controlled student and teaching staff participation and include all types of teaching material such as lecture notes, slides, handouts, homeworks, problem set examples, coursework assignments, videos of lectures and demonstrations, electronic reading material, etc. The information can be managed promptly and efficiently, being made available to students when it is relevant. It sends reminders, announcements and allows creating individual calendars tailored to each participant's needs. Digital content can be created and uploaded by both teachers and students. The content can be shared through a cloud space dedicated to a specific assignment or in a discussion forum.

All the examples listed above to some extent fall within categories that have already been introduced more formally on the list of active learning types presented in Section 2 and in the discussion of digital technologies in Section 3. These examples however provide a summary of current state of affairs in the more traditional education currently being practiced in teaching advanced nuclear systems curricular across European universities and in particular those participating in the ESFR-SMART project.

6. Discussion and conclusions

Because of the demographical decrease in the number of youngsters in the post baby boom era combined with the general lower interest in natural sciences, and in physics and mathematics in particular, the number of students in those areas has been constantly declining for the past years in Europe. In the field of nuclear engineering, additional factors related to phasing-out programs being implemented in various countries and to nuclear energy not being societally and politically accepted in general, fewer and fewer students choose a nuclear education.

As a result, the area of tertiary education has become increasingly competitive, where each university and, within each university, each program try to attract students. The recent increased attention in engineering education to innovative pedagogical approaches having student learning in focus is a clear demonstration of such a highly competitive situation. Moreover, with the massive deployment of various digital educational resources and tools, the combination of active learning techniques with blended learning represents an appealing and important feature to students, especially considering the fact that they wish to be more and more in control of their learning.

For nuclear engineering education to “survive” in this situation, it is essential that such new pedagogical approaches are also implemented in the existing and future curricula. As demonstrated in this report, the combination of active learning techniques and blended learning results in far greater learning outcomes. In the area of nuclear engineering and despite the decrease in the number of nuclear engineers being educated, the implementation of such techniques would lead to nuclear engineers much better equipped with skills to tackle complex problems, requiring both a deep knowledge of the field and a critical approach to those.

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