EXPERIMENTS IN CREATING ONLINE COURSE CONTENT FOR SIGNAL PROCESSING EDUCATION

C.-G. Jansson, R. Thottappillil

KTH Royal Institute of Technology
School of Electrical Engineering
and Computer Science
10044 Stockholm, Sweden

S. Hillman, S. Möller

Technische Universität Berlin
Quality and Usability Lab
10587 Berlin, Germany

K V S Hari, R. Sundaresan

Indian Institute of Science
Dept of ECE and the Robert Bosch
Centre for CPS
Bangalore 560012, India

ABSTRACT

The creation of the NPTEL platform in India has led to a vast population of engineering students getting access to quality online content for Signal Processing. These courses are globally accessible, free of cost, and also provide a means of obtaining certificates of proficiency by taking a proctored examination. Recently, a European Union funded project, MIELES, has supported the activity of creating online courses in the fields related to Signal Processing. This paper presents the details and experiences of creating course content and presents guidelines for prospective content creators.

Index Terms— Online learning, eLearning, blended learning, NPTEL, assessment

1. INTRODUCTION

The advent of e-learning platforms has transformed Signal Processing (SP) education in recent years. Learning the fundamentals of Signal Processing through traditional classroom teaching, using well written textbooks, has thus far been the norm for students. This mode of learning is dependent on the quality of trained educators who use printed material, black/white boards, presentation material and interaction in classrooms. The impact of poor quality delivery of content can adversely impact the understanding of critical SP concepts. This issue becomes even more critical when the number of poor quality educators is large, for example in the Asia-Pacific region. In order to address this issue, several initiatives that use the powerful digital medium of online content delivery have taken shape [1, 2, 3]. In this paradigm, the content is created by an experienced educator in the form of recorded video lectures. These are then edited and uploaded to a content delivery platform accessible to interested students across the globe. This provides access to good quality content which students can use to learn at their own pace. Adequate interactive sessions with the educators and their assistants greatly enhances the learning experience of the student. The power of such online platforms is that it democratises access to good educational content and enables good educators to have a greater reach for large scale impact. The above model has been successfully adopted by many institutions and one such example is the NPTEL initiative in India [4], which is described in Section 3.

The next important component in formal learning is the assessment of the level of learning, in a way that is acceptable to HEIs (higher education institutes) and industry. In the traditional settings, this is based on handwritten examinations, some of which may require descriptive answers which are then assessed by the instructors and their assistants [5]. For online learning platforms, however, a new paradigm is needed to create a scalable assessment methodology which is also credible and acceptable to HEIs and industry. This credibility and acceptability requirement is resolved via proctored handwritten and/or electronic exams conducted by a reliable institution at several geographical locations.

Another import aspect is the value attached to the assessment by an institution, upon a student's completion of such online courses, towards meeting the credit requirements of the institution's course or degree programme. This is a policy matter for the institution.

Considering all these issues related to online learning, a joint activity between European and Indian academic institutions was proposed. The activity called MIELES[1] had the objective of developing a strategy to utilise the power of online learning to enhance the learning experience of learners in their respective institutions and also to contribute to the overall knowledge network in India and Europe. This paper provides a glimpse of the initial steps taken. Several institutions have deliberated thoroughly on the implications of adopting online learning to enhance the quality and user experience for the learners and the needed shift in the administrative policies of academic institutions to embrace such new and powerful learning platforms. In the conclusion section, we will discuss a framework that is evolving in India under which institutions extend credit to students who have completed such online courses.

2. TERMINOLOGY

E-learning refers to the substantial use of information and communication technology to support learning in a specific context. Online learning refers to the systematic provision of course material via the world-wide web (WWW). The size of the pieces of material can vary from very small pieces ("nuggets"), via sections of courses, complete courses, or even complete programs.

The most common form of use of online learning is blended learning, by which we mean a still traditional form of campus-based education, but one where online material is used in a systematic way and is integrated with other learning mechanisms. The online components of blended learning are still limited to mappings of the traditional classroom settings.

Acknowledgment: This work was funded by the European Commission in frame of the Erasmus+ project MIELES (https://mielesproject.org, Ref. 573708-EPP-1-2016-1-ES-EPPKA2-CBHE-JP).

[1]Modernizing & Enhancing Indian eLearning Educational Strategies, `https://mielesproject.org/`.

The more traditional and familiar distance learning is another concept that has existed for a long time, and is often enabled by actors that are not HEIs. Traditionally distance learning did not use digital aids, but there is now a gradual transformation into an online learning form. One extreme of distance education realised by e-learning methods is a Massive Open Online Course (MOOC) which is a stand-alone online course allowing free participation and open access via the WWW. MOOCs can be either self-paced or non-self-paced. In the former the learner can use the course material without any restrictions; in the latter, the course material is intended to be used under supervision, and according to a fixed schema. MOOCs are provided by Individual HEIs, Consortia of HEIs or non-HEI online-learning commercial course providers (e.g. Coursera, EdX, Udacity, Udemy and Sailor).

We can also see some developments in establishing large repositories of e-learning fragments or nuggets (in the order of 5-10 minutes) that can be accessed without any imposed structure. This can be subsets of YouTube clips or more specialised repositories.

3. NPTEL

The National Programme on Technology Enhanced Learning (NPTEL) [4] was initiated by the seven Indian Institutes of Technology (Bombay, Delhi, Kanpur, Kharagpur, Madras, Guwahati and Roorkee) and the Indian Institute of Science, Bangalore in 2003. The requirement for trained engineers and technologists is far more than the number of qualified graduates that the Indian technical institutions can currently provide. The number of institutions having fully qualified and trained teachers, in all the disciplines that are being taught, constitutes a small fraction. A majority of teachers are young, inexperienced and are often undergraduate degree holders. Therefore, it is important for the reputed and established institutions like the IITs, the IISc, the NITs and the other leading Universities in India to disseminate teaching/learning content of high quality through all the available media. NPTEL was started to serve this need, as a MOOC platform.

NPTEL is the largest online repository in the world of courses in engineering, basic sciences and selected humanities and social sciences subjects.The NPTEL YouTube channel is the most subscribed educational channel with more than 1.5 million channel subscribers and more than 471 million views. The platform has more than 56,000 hours of video content with more than 52,000 hours of transcribed content and over 51,000 hours of subtitled videos. It is also one of the most accessed libraries of peer-reviewed educational content.

NPTEL also offers certificates by conducting proctored examinations. These are held at more than 100 locations in India on a regular basis. The offered certificates are also being considered by some academic institutions to meet the credit requirements for their degree programmes and for inclusion in the transcripts.

4. SIGNAL PROCESSING EDUCATION THROUGH NPTEL AND MIELES

Signal Processing courses are taught in more than 6,000 engineering colleges in India, by about 25,000 educators. The competence levels of these educators vary a lot and NPTEL courses supplement the classroom delivered content. NPTEL has about 20 signal processing courses which includes basic courses on signals and systems, analog signal processing, adaptive signal processing, video processing, wavelets, architectures, biomedical signal processing, and neural networks for signal processing. The recent interest in Machine Learning and AI has also triggered courses based on these topics. At least 6 courses on Machine Learning have been offered and have been very popular.

The most popular NPTEL course on Digital Signal Processing has attracted over half a million views on YouTube. The recent course on Machine learning has attracted more than quarter-million views. The feedback on these courses is tremendous and many have obtained certificates after taking an NPTEL administered proctored exam. The Indian industry has started to recognise these certificates, and this has bolstered the prospects of students to get a job. These courses are well structured and have been well received by many students not just in India but also in many other countries around the world.

In the MIELES project it was envisaged that this powerful online education platform could be utilised to create courses in signal processing and machine learning by international faculty members. This would expose students to a different style of teaching and would enrich their learning experience. We could also explore the use of autogradeable assignments. The courses offered by faculty from KTH Royal Institute of Technology (KTH) and Technical Universität Berlin (TUB) were based on signal processing and machine learning.

5. COURSES DEVELOPED AS PART OF MIELES

Three new courses for NPTEL have been produced within the framework of MIELES. All three were run in a non-self-paced mode between January and April 2019. Short descriptions of the courses are given in the following and Table 1 shows basic statistics about the students and exams. In each course, the exam carried 75 % weight and the weekly assignments carried 25 % weight of the final score.

5.1. Machine Learning

KTH offered a course in Machine Learning on the NPTEL platform. This is a basic yet comprehensive course on Machine Learning. The key theoretical course modules are:

- Supervised and unsupervised inductive learning with a minimum of domain knowledge including learning of decision trees, genetic algorithms, instance-based learning and conceptual clustering;
- Learning on the border of a strong domain theory including inductive logic programming, explanation-based learning, case-based reasoning and reinforcement learning;
- Artificial neural networks including Perceptrons, multi-level feed forward neural networks, Hebbian learning, Boltzman machines, Recurrent networks and Convolutional networks.

The course also covers application areas and case studies as well as tools and development platforms. It is an eight week course, with approximately 40 video lectures within 25 hours of video content and weekly assignments. The style of teaching is monologue presentations based upon power point presentations. The NPTEL team produced text transcripts of all videos. NPTEL organised a small group of teaching assistants that not only handled the student contacts but also helped with reviewing the lectures and the assignments. Assignments and exams were auto-gradable.

5.2. Electromagnetic Compatibility

There is an existing course on Electromagnetic Compatibility (EMC) at KTH, given as a traditional classroom plus laboratory course for the Masters students with a background in Electrical Engineering.

Typical class sizes are 15 - 20 students. The online-version of the EMC course is unique within the NPTEL course offerings as there was no other course devoted to the subject. The main contents of the course includes an introduction to the concept, explaining the typical causes of electromagnetic interference (EMI), its modelling using concepts in electric circuits and electromagnetism, and discussion of mitigation strategies for EMI to achieve EMC, along with numerical examples. This was an eight week course, with approximately 30 video lectures with 20 hours of video content and weekly assignments. Assignments and exams were auto-gradable. The style of teaching was monologue presentations based upon power point slides.

When compared with a paper and pen based examination of the KTH off-line course, the greatest challenge for the online course was in preparing auto-gradable assessment questions that could properly assess the learning outcome and evaluate the critical thinking capability of the students. Another challenge faced was the inability to provide hands-on experience through laboratory exercises. The inability to get direct on-the-spot feedback and questions from students was another drawback although, to some extent, this was alleviated by the use of an online discussion forum.

5.3. Multimodal Interaction

Due to the absence of courses related to multimodal interaction on the NPTEL platform, TUB provided and supervised the course Multimodal Interaction (MMI) [6, 7, 8, 9]. The course sets the basics for an understanding of multimodal communication between humans and multimodal interaction between humans and machines.

The course describes first the physical, cognitive and psychological processes taking place in humans when perceiving auditory, visual, and tactile signals, as well as how these perceptions are integrated in order to form multimodal perception. Such signals can be generated and received by machines which enables such systems to interact with humans in limited domains. The setup of such machines and systems as well as usage of signal processing is discussed in the middle of the course. Finally, the course gives an introduction into the most recent application of multimodal human-machine interaction, namely augmented reality, virtual reality and the continuum between both and reality (i.e. mixed reality). The main topics covered by the course are:

Human-related: Hearing and speech, vision, other senses (e.g. Olfactory and tactile sense), integration and cognition, multimodal perception, human multimodal interaction

System-related: Multimodal input and output systems (e.g. automatic speech recognition and text-to-speech synthesis), multimodal interactive systems, virtual environments

The course is relevant for undergraduate students not only in the computer science stream but also in all other engineering streams which may involve human-computer interaction, for e.g., students who may need to program user interfaces or develop related technology (as in development of embedded systems for audio processing).

6. NOTEBOOK ENVIRONMENTS FOR INTERACTIVE ONLINE LEARNING

Signal processing is perhaps best learnt by doing. After learning a new concept, students could immediately write short programs involving the concepts learnt and run them on test signals to verify outputs. When the outputs match, this instils confidence, reinforces understanding, and drives them to go forward. When the outputs do not match, if the tasks are well-designed, the snippets of code are sufficiently short to enable easy debugging. The successful debugging effort often leads to an even better understanding, sometimes beyond what was originally envisaged by the instructor. We now describe how this learn-by-doing paradigm can be embedded in NPTEL courses on SP.

		Exam		
Course	Enrolled	Registered	Present	Passed
ML	38,449	2,182	1,600	1,287
EC	2,145	147	87	66
MMI	432	105	95	62

Table 1. Number of enrolments and students in the exams in the three courses, Machine Learning (ML), Electromagnetic Compatibility (EC), and Multimodal Interaction (MMI).

Let us consider the simple goal of introducing students to filtering and the process of generation of an autoregressive and moving average process (ARMA). The following tasks constitute a learn-by-doing exercise. We will discuss the interactive and online nature subsequently.

1. Coding exercise: Introduce the finite impulse response (FIR) filter, for e.g., the filter with the z-transform $1 + az^{-1}$.
2. Coding exercise: Introduce an infinite impulse response filter $1 + az^{-1} + a^2z^{-2} + \ldots$, $|a| < 1$, its working on the infinite past, and its approximation by an FIR filter.
3. Narrative: If the students are familiar with z-transforms, provide a narrative on why this is $(1 - az^{-1})^{-1}$.
4. Coding exercise and validation: Introduce the autoregressive (AR) part and its implementation in time-domain via $y_t = x_t + ay_{t-1}$. Students then check against previously generated outputs that used approximate FIR filtering.
5. Validation: Highlight the importance of initialisation. Some programming environments result in NaN (not a number) if not properly initialised.
6. Coding exercise: Implement more complex ARMA processes, for e.g., $\frac{(1-a_1z^{-1})(1-a_2z^{-1})}{(1-b_1z^{-1})(1-b_2z^{-1})}$. Do it step-wise: first the first FIR filter, then the next FIR filter, then the AR filter . . ..
7. Exploration: Interchange component filters and observe the outcomes and come up with an invariance hypothesis.
8. Exploration: Understand why $|a| < 1$ for the AR filter $(1 - az^{-1})^{-1}$, and what happens when $a = 1$, $a = -1$, etc.

At each stage test inputs and anticipated outputs could be provided, and the students could match their outcomes against the anticipated outputs. For scalability, the interaction should with the computer, but the Instructor controls the narrative by dividing the larger ideas into easily swallowed smaller capsules with clear indicators of progress to keep the students motivated.

The above could be done via "Notebooks". The instructions, narratives, pictures, mathematical equations, code, with some written by the instructor and some by the student, and the output, all appearing in a single document, provide a workflow that promotes interactive learning. Example environments include Jupyter, Eclipse, PyCharm, Selenium IDE, etc. These also support a variety of programming environments (Python, R, etc.). The Notebooks are also easy to share with the students. The students' additions and computing outcomes are easily shared for feedback or evaluation, if needed.

Using simulation with rich visualisation, Notebooks can help create a Virtual Laboratory and perhaps go beyond. For example, if the transmission line parameters in an EMI experiment are changed, a simulation and subsequent visualisation of the resulting electromagnetic interference can enhance understanding.

A Notebook such as the above was used to expose high school students to Kepler's analysis of Brahe's data, and Kepler's inference that Mars's orbit around the Sun is an ellipse with the Sun at one focus [10].

7. CONCLUSION AND FUTURE WORK

This effort has been performed in the context of Electrical Engineering and Computer Science where Signal Processing in a wide sense constitutes a cornerstone in most education programmes.

Increased mobility of students in several dimensions is raising the demands for more flexible forms of education relative to the traditional monolithic textbook, classroom and campus-based education. Scale-up of higher education also puts demands on sharing of quality course content across heterogeneous HEIs.

On-line learning is one promising avenue to achieve flexibility as well as uniformity in quality. However, the traditional technical universities are still conservative in moving in this direction and faster progress and innovations are clearly called for

Our Europe-India collaboration has meant considerable progress for both parties. The challenging HEI arena in India has triggered the establishment of on-line provision frameworks such as SWAYAM, a broader platform that hosts courses taught from Class IX [11], and NPTEL that in many respects are superior to the mechanisms so far established in Europe.

One strength of the Indian approaches are the strong partnerships among HEIs of high standard exemplified by NPTEL. We strongly believe that this way forward is superior to the setup of commercial middlemen with HEIs as subcontractors for provision of on-line courses that dominates the scene in US and Europe.

Our efforts where two European Technical Universities have developed three on-line courses within the NPTEL framework has given the European partners a profound insight into the Indian setups in this respect.

In the opposite direction our experiences have led to useful feedback to the Indian partners. Among all:

- Proposals for improvement for course descriptions moving from syllabus to learning outcome oriented descriptions;
- Improvement of the tight connections between learning outcomes, design of learning sessions and assessment tasks;
- Improvement of modes for formulation of assignments of problem solving nature;
- Initial ideas for a design of virtual lab components in the on-line course designs.

Finally our work has triggered an important discussion on how to build up trusted relations in networks of HEI's that can be the basis for securing student's rights to acquire formal university credits based on the certificates that so far merely document the on-line course achievements.

8. ACKNOWLEDGEMENT

Regarding all courses which were created in frame of MIELES and are presented in this paper, we want to thank the different teams at NPTEL for their support in during the creation of the courses, exams and assignments as well as for the transcription of all videos. Furthermore, the large number of students in the machine learning course was only possible through the strong support by the teaching assistants.

Many thanks to Dr. Benjamin Weiss, Prof. Dr.-Ing. Jens Ahrens (Chalmers University of Technology) and Ph.D. Rahul Swaminathan for their contributions to the course Multimodal Interaction. Furthermore, the recording and final production of the videos were strongly supported by the Center for Continuing Scientific Training and Cooperation[2] of TUB. Thanks are also due to Ramesh Hariharan and Pulkit Singh for the Mars orbit lectures and creation of the Mars orbit Notebook, respectively.

9. REFERENCES

[1] M Rocío Martínez-Torres, FJ Barrero García, SL Toral Marín, and S Gallardo Vázquez, "A digital signal processing teaching methodology using concept-mapping techniques," *IEEE Transactions on Education*, vol. 48, no. 3, pp. 422–429, 2005.

[2] SL Toral Marin, FJ Barrero Garcia, R Martinez Torres, S Gallardo Vázquez, and AJ Lillo Moreno, "Implementation of a web-based educational tool for digital signal processing teaching using the technological acceptance model," *IEEE Transactions on Education*, vol. 48, no. 4, pp. 632–641, 2005.

[3] RF Jinks, "Knowledge... understanding (mind the gap!)[electrical engineering education]," *Engineering Science and Education Journal*, vol. 5, no. 5, pp. 227–230, 1996.

[4] "National Programme on Technology Enhanced Learning (NPTEL)," `https://nptel.ac.in/`.

[5] Kathleen E Wage, John R Buck, Cameron HG Wright, and Thad B Welch, "The signals and systems concept inventory," *IEEE Transactions on Education*, vol. 48, no. 3, pp. 448–461, 2005.

[6] "Multimodal Interaction, NPTEL course webpage," `https://onlinecourses-archive.nptel.ac.in/noc19_cs34/`.

[7] Sebastian Möller, *Quality of Experience: Advanced Concepts, Applications and Methods*, Springer, Berlin, Heidelberg, 2010.

[8] Niels Ole Bernsen and Laila Dybkjaer, *Multimodal Usability*, Springer, London, 2009.

[9] Ramón López Cózar Delgado and Masahiro Araki, *Spoken, Multilingual and Multimodal Dialogue Systems: Development and Assessment*, John Wiley, Chichester, England ; Hoboken, NJ, 2005.

[10] "data analysis course module on kepler's analysis of mars's orbit," .

[11] "The SWAYAM Programme," `https://swayam.gov.in/about`.

[2] https://www.zewk.tu-berlin.de