From Scratch to Hatch: Designing an evidence-based entire semester for optical engineering students

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FROM SCRATCH TO HATCH: DESIGNING AN EVIDENCE-BASED ENTIRE SEMESTER FOR OPTICAL ENGINEERING STUDENTS

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Evidence-based approaches in teaching and learning provide strategies to empower student learning and long-term retention of knowledge. Such strategies can be implemented at the course level by a single teacher, which then happens at a smaller scale. However, a more powerful approach consists in a coherent integration of neuroeducational principles in the entire structure of a term, involving several courses over several months. This represents an educational change at a higher scale, however facing several risks in its in-practice implementation, such as faculty reluctance and resource insufficiency. We report here on the design of a whole academic term for optical engineering students in dual education at the Bachelor level. It was devised in order to maximize retention effects through a coherent and coordinated use of constructive alignment in course design, active learning activities, metacognition course, and spaced learning. The design process is encompassed within a SoTL (Scholarship of Teaching and Learning) methodology cycle. It involved a total of 12 faculty members, led by a core group of six, trained by educational advisors in neurodidactics, and tasked with the global design, planning and management of the project. At the pre-roll out stage, this work delivered collectively elaborated timetables, syllabus, balanced student workloads, and plans for team teaching and shared educational tasks.

Keywords: Evidence-Based Approaches, Higher Education, STEM Education

INTRODUCTION

Long term retention of knowledge and skills is a good indicator of the efficiency of many teaching activities and pedagogical approaches, common to almost any field at any educational level. It is a solid criterion: indeed, deep learning is often a prerequisite to favor fast and efficient retrieval of previously learned material. Nevertheless, teachers reporting students having trouble with retrieval and retention of learning outcomes is a widespread experience – a serious challenge for students expected to review and master an ever-growing amount of material.

Recent references in the field of evidence-based approaches to teaching and learning, as well as neuroeducation and cognitive psychology, provide recommendations for the design of courses and curricula (Masson, 2020; Latimier, 2019). Course design guides have also been made available, but their in-practice implementation is usually rather poorly documented (Roediger & Pyc, 2012), and noteworthily, is mostly exemplified by smaller scales approaches, at course levels. Besides, neuro educational principles are sparsely used across disciplines and institutions. The pursued research objective was to *develop a research-based academic term at the Institut d'Optique Graduate School (IOGS), a French engineering school specialized in optics & photonics*.

150 new students are enlisted at the IOGS each year. They follow a 3-year track (6 terms), starting at the senior year of undergraduate studies and graduating with a French "Diplôme d'Ingénieur", comparable to a Master of Science in optical engineering (see Figure 1.). The scientific training at IOGS is highly specialized in optics & photonics. It involves a significant fraction of fundamental physics courses, complemented with pratical training during labwork sessions. Around 35% of all students at IOGS decide to complete their MSc in optical engineering with a PhD track.

The current teaching approach at IOGS follows the path most frequently encountered in the French higher-education system: the different courses combine a significant amount of formal lectures delivered to the whole cohort of 150 students, followed by several tutorial sessions in smaller groups, typically between 25 and 30 students. Evaluations consist generally in one final written exam. In their curriculum at IOGS, the students have a heavy experimental labwork sessions program, with weekly reports to handle back.

This study focuses more closely on a cohort of 25 students registered in dual-education. Over the course of these 3 years, students in dual-education spend 50% of their time working in a company, and 50% of their time studying at IOGS following the same courses as other students. Students in dual-ed display no specific differences in their professional future compared to other students of the school, as assessed by post-graduation surveys.

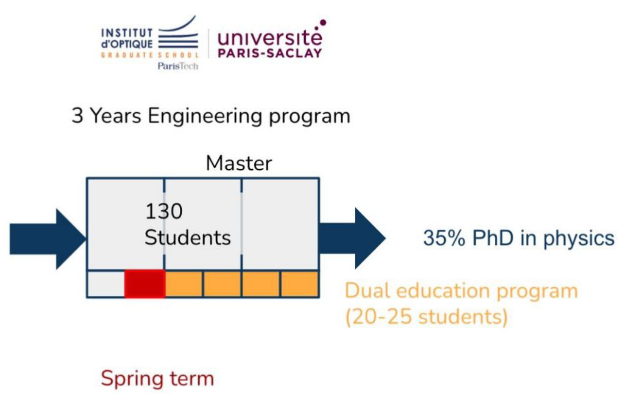

Figure 1. Structure of the Engineering program at IOGS.

This paper reports about the redesign of the second term of a 6 terms academic program for a subset of 25 students among a total of 150 students, it is expected to provide an enhancement of the retention of knowledge acquired during this term over the second and third term of the programme) for these 25 students compared to the remaining 125 students still working with "traditional" lecturing system.

In this paper, we report about the carried design process of the second term of the first year of the engineering track at IOGS, for these dual-ed students. This term is based on seven scientific courses (Polarization, Semiconductor Physics, Electromagnetism, Scientific Computing, Signal processing, Labwork in Optics, Laser Physics). We report about the pedagogically renovated term that resulted from it. The term was conceived in order to maximize long-term retention of knowledge and skills acquired by undergraduate students and expected to provide, in comparison to the traditional "lecturing" system, a solid ground for students to master new material along their entire curricula. This process was based on the implementation of four different strategies, thought as *design rules* for this term: *constructive alignment of courses*, *active learning activities*, *timetable management respectful of spaced learning*, and *metacognition* related activities.

THEORETICAL CONCEPTS

Constructive alignment is a method that aims at building coherence between intended learning outcomes, assessments and learning activities (Biggs & Tang, 2011). It favors deep learning in contrast to surface learning (Ramsden, 2005). It also enables us to quantify and evaluate teaching strategies efficiency.

Active learning practices refer to a variety of activities, such as problem-based approaches, favoring students' cognitive involvement in their own learning process, and enhancing their global performance.

Spaced practice and interleaving are key enablers to long term retention of knowledge and skills, in contrast to massed uninterrupted practice (Latimier, 2019).

Metacognition is about making students aware of their own thought and memorization processes, and to provide strategies to regulate and improve their cognition. Such awareness can improve students' engagement and performances (Sarrasin et al., 2018).

METHODS

The redesign of the whole term involves 13 faculty members of the IOGS, in charge of the 7 scientific courses. We describe here the workforce organization. The *design-based research process* was carried out by a "core" leading team of six teachers (professors), among the whole group of 13 involved in the redesign of the term. For each of the seven scientific courses, a team of two faculty members, including one member of the core team, was formed, and designated in charge of the specific redesign tasks for the course.

Over the course of the project, the core team members interacted with experts in higher-education pedagogy from the Université du Québec à Montréal (UQAM) as participants to an action-research process supervised by the university's department for innovative pedagogy (Research Action Chair on Educational Innovation at Université Paris-Saclay) (See Fig. 2). The design-based process was inspired by the six-step SoTL (*Scholarship of Learning and Teaching*) methodology cycle proposed by Bélisle et al. (2008).

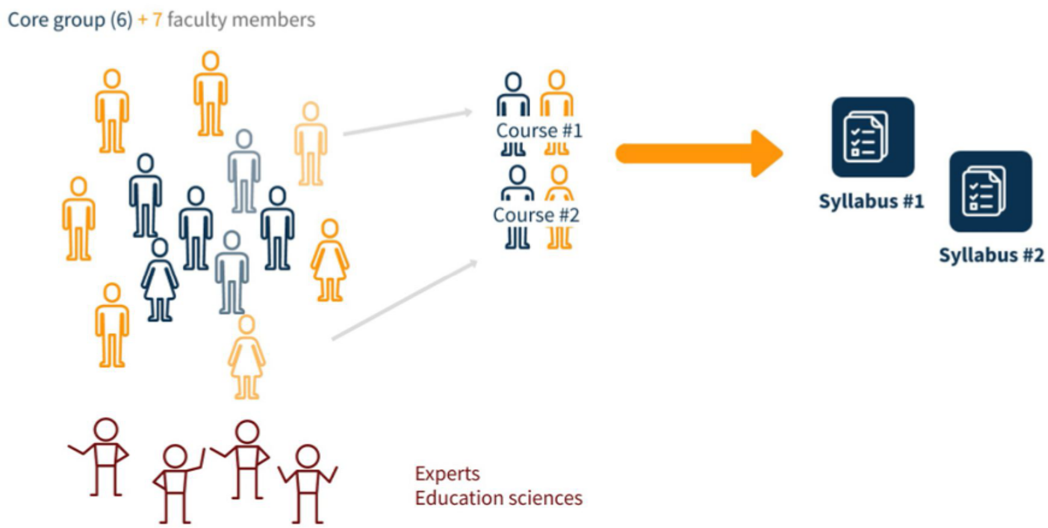

Figure 2. Workforce organization.

The design process involves a group of higher-ed experts training a subset of 6 teachers (the "core" team) among the 13 faculty in charge of the scientific courses taught during the term. Each of course is re-designed by a team of 2 faculty, one of them from the core team.

The project was initiated during a one-week kickoff workshop of the action-research programme in December 2019. The core team got trained on neuro didactic principles and active learning activities by the experts. During this first week, the core team wrote a first draft of the project, clarifying the different design rules to be followed in the redesign process (constructive alignment, spaced learning, metacognition, active learning). Supervised bibliographic works were collectively carried out to further dig the concepts and the methodology to be implemented in the design process.

After this initial training stage, the core team regularly regrouped with the rest of the educational team in order to propose a unified perspective on the project that would allow the coherent implementation of the four pillars of the project, as well as to set a recurring framework for all faculty to continuously progress in the re-design process of their own course (see Transfer/Harmonization step in Table 1) The core team organized a series of meeting for this step, based on feedback discussion of the initial workshop session, discussion of scientific articles and peer instruction during activities, such as the redaction of learning outcomes.

In parallel, the members of the core team took in charge project management tasks. A shared online space was created to store all documents related to the project, such as minutes of meetings, reports, bibliography, timetables, and all digital resources. All resources were accessible to all faculty and experts involved in the project. A shared logbook was also created, keeping track of the different milestones of the project, date after date.

Other resources listed as "tools" were created by the core team, in order to ensure as much as possible the harmonization of practices and the compliance to design rules during the design process. First, a syllabus template was redacted. This template was written to be in adequation with constructive alignment principle. It was provided to all faculty, in order to gather for each of the 7 scientific courses the learning outcomes, the evaluation principles and the planned teaching activities. A catalog of learning activities in an active teaching perspective was also provided. The redacted syllabus were later collected and made available to all teachers. Secondly, a provisional timetable was shared in order to provide an overview of student assessment activities and of the global student workload. Faculty were asked to list their planned activities including the assessment activities and to estimate the time that students will spend of each task. This shared document was used to iteratively design a timetables and tasks to avoid brief work overloads, but also to synchronize the progress of several courses. For example, some notions related to light propagation in matter are present in both the Electromagnetism course and Polarization course learning outcomes. Connections between courses could be established more easily after discussions and interactions based on the respective syllabus and retroplanning of both courses.

Finally, the adequation of the proposed design with all four pillars was discussed during regular consensus meetings or with experts. These meetings serve as validation steps of the design process. The different steps of this elaboration process (adapted from Bélisle et al. (2018) are presented in Table 1 along the four axes of the project.

In practice, this workforce organization was based on regular interactions between higher-education experts and the core team for training and feedback purposes on one hand, and interactions between the core team and other faculty for peer instruction, harmonization of practices and actual implementation of the design rules on the other hand. During the design process, around 30 meetings were set over the course of a year, between December 2019 and the official start of the term in February 2021.Strategies of pre- and post-testing of students along the implementation of the project were designed to monitor the performances of the reference student cohort experiencing the “traditional” lecturing approach of teaching.

Table 1. A summary of methodological steps taken in the design process.

<table>
<tr><th></th><th>Initial training</th><th colspan="2">Transfer/ harmonization</th><th>Tools & methods</th><th>Validation</th></tr>
<tr><td>Constructive alignment</td><td rowspan="3">Training by experts (seminars, coaching during the action research process)
Supervised bibliographic search</td><td rowspan="4">Consensus meetings

Journal clubs

Peer instruction

Feedback about the experience</td><td>N/A</td><td>Work by pairs – syllabus redaction</td><td>Consensus meeting</td></tr>
<tr><td>Active learning</td><td>2-days training</td><td>Activity catalog</td><td>Consensus meeting</td></tr>
<tr><td>Spaced learning / interleaving</td><td>N/A</td><td>Timetables</td><td>Consensus meeting</td></tr>
<tr><td>Metacognition</td><td>Bibliographic search</td><td>N/A</td><td>Feedback from experts and peers</td><td>Feedback from experts and peers</td></tr>
</table>

Several points are to be noted with our methodology. While the scientific perspective of building a system dedicated to the improvement of long-term retention of knowledge is at the heart of the design process, the implementation of a change in pedagogical practices was also strongly motivated by the need to comply to new requirements established by the institution certifying the French Diplôme d'Ingénieur. THis created a concrete sense of urgency, and a need and energy for a curricular change shared among faculty, therefore significantly different from change implementation based on more individual initiatives at the individual course level.

In many aspects, our methodology follows the first steps of the Kotter's change model in the context of engineering education reform by Froyd et al.

RESULTS

The academic term involved seven physics related courses (*Electromagnetism*, *Polarization*, *Semiconductor Physics*, *Laser*, *Scientific computing*, *Signal processing*, *Labwork sessions*) along with metacognition workshops and foreign languages, for a total of 210 hours of in-class presence.

The following paragraphs briefly describe the training formats that were developed at the end of the development cycle:

Spacing/interleaving. Students worked in a dual-education program and shared their presence time between campus and companies. The semester was globally restructured, so that students alternated between three week periods of on-campus work and three week periods of internship time. During campus time, weeks were divided into time slots so that each course was delivered during two 90 minutes time slots on different weekdays (See Fig. 3). This organization results from logistical constraints discussed during consensus meetings, such as teaching or research duties of faculty members.

Figure 3. Timetable and semester schedule.

The spring term of the dual education program lasts 19 weeks, including 9 weeks of full-time internship. Considering the sleep agenda of the students, courses start late in the morning during the weeks of attendance at school.

Constructive alignment. Teachers worked similarly to a think-pair-share scheme, working in pairs of disciplines to share experience and personal research on the topic. All teachers were asked to fill in a descriptive form of their strategy, detailing their intended learning outcomes, assessments tasks and learning activities. Validation of the forms were carried out during consensus meetings and formed a basis for syllabus. This work enabled also to evaluate the students' workload during the semester, to envision synchronization of courses between disciplines and a better repartition of intended learning outcomes (avoiding unnecessary repetition across different courses, sharing same vocabulary, notations, identifying student misconceptions).

Active learning. All courses have introduced active learning activities as part of their teaching strategy. For example, the Electromagnetism course was delivered in a flipped-classroom format. The Laser physics and Semiconductor physics courses introduced case studies and problem based learning activities, etc. Some of the activities also included formal or informal assessments, providing opportunities to give students feedback more regularly along the term.

Metacognition. Weekly metacognition workshops were part of the students' schedule. Sessions focused on a description of cognitive and brain processes and their connection to learning practices, as well as their perceived effectiveness. (See Fig 4.)

Figure 4. Themes addressed during the metacognition workshops.

While not explicitly put in the initial objectives of the projects, additional dimensions arose during the design process: implementation of regular assessment and self-assessment tasks to the students (and related discussion on the repartition of in-class and at-home workload of the students); the time of the first lesson in the morning was set at 9:30 am, 30 minutes later than usual, as an effort to take into account the students sleep time.

This new design was implemented for the first time in February 2021 for a first cohort of students. Evaluation of the courses by the students was carried out to get feedback from the student's perspective through an online survey at the end of the term. A vast majority of students showed highly enthusiastic and positive about the general perspective of being part of an educational change strategy, and expressed a significant interest and satisfaction with the new teaching strategies, in contrast with their previous experience with traditional lecturing. Interestingly, as this cohort was affected by the pandemic, remote teaching was also introduced, but incorporating remote active learning strategies. While students of the reference cohort in contact with "remote traditional lecturing" reported a very low satisfaction rate, we observed a marked contrast with the studied cohort, displaying a satisfaction rate for the "remote active learning" activities in par with physical class.

In parallel assessment of student performances revealed no specific difference, neither positive or negative between students from the reference cohort and students under the revised term. A series of tests are introduced for the rest of their curriculum in order to evaluate the possible effect of this new term on long-term retention.

CONCLUSION

In this paper, we reported about the design of a whole academic term trying to maximize the outputs of a coherent use of spaced practice and interleaving, course design based on constructive alignment, use of active learning practices and awareness of students to metacognition aspects. This project was led at an intermediate scale, involving 13 teachers leading 7 courses, overcoming limitations of a single course implementation of similar strategies. The design was carried out using a team organization based on a core group of six teachers in charge of the global project management, interacting with experts and getting trained on the key aspects of the envisioned pedagogical practices, and then working with the rest of the group to share experience, provide resources and tools and validate elaboration steps during consensus meetings. The impact of the semester on the long term retention of knowledge and skills by students will be monitored during the rest of their time on campus, thanks to a pre-test post-test strategy for which the results will be used to adjust the educational change strategy.

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