EXECUTIVE SUMMARY: LAYING NEW FOUNDATIONS

Education at EPFL is at a crossing of many roads. In a short span of ten years, the number of undergraduate students in our school as doubled, while our requirements on foreign students’ admissions have tightened. Yet the success rate at the end of the first year decreased significantly over the same period. At the same time, great debates on education have emerged. Fueled by the 1.5 trillion dollars’ students loan crisis in the US, the value proposal of higher education has been questioned by policy makers, sociologists and economists. The digital revolution hit the traditional classroom model, offering new pedagogical horizons but also suggesting a major disruption was on its way in the wake of a renewed enthusiasm for online education.

This is a key moment to discuss and lay new foundations for the EPFL educational model. Is it still adapted to the population of students joining first year? Do we prepare them well enough for the rest of their studies? What are the most critical tools an EPFL graduate should receive during their education? How should we organize our study plans and pedagogy to answer these challenges?

A Task Force on Education was assembled by the Vice-Provost for Education and mandated to answer these questions. The present report summarizes the conclusions of the Task Force, which are built around three pragmatic recommendations:

1. A stronger focus on polytechnic foundational topics (the Polytechnic Core) and few breadth topics, enabling students to work in depth on these disciplines with an increased emphasis on personal work.
2. A clear definition of the Polytechnic Core based on disciplines aiming at developing rigorous developments, the capacity to abstract and model as well as computational thinking.
3. An emphasis on pedagogical innovation, building on increased personal work, fueled by teachers’ enthusiasm and the digital revolution.

These recommendations should be implemented in first year as soon as possible, but should also serve as guiding principles for our entire educational philosophy. It is a strong conviction of the Task Force that these recommendations will help students obtain stronger foundations and an increased capacity to learn autonomously. This will in turn help them face the many challenges of education at EPFL but also prepare them for a lifelong of learning in the face of accelerated technological developments in the workplace.
Recommendation 1: A stronger focus on the basics and on personal work

Background & Analysis
There are clear warning signs that the organization of the EPFL “propédeutique” cycle does not allow our student to develop a strong polytechnic basis. Not only does this result in shaky foundations to build knowledge, there is a growing concern that healthy work habits do not develop either and may just be one the principal causes of the growing failure rate in first year (Fig. 1).

![Figure 1: Evolution of the success rate at the end of the 1st year](image1.png)

When focusing on Swiss nationals and residents, the situation is even more dire as shown on Figure 2. The success rate of students with a Swiss diploma, not including second tries, is now at 34%.

![Figure 2: Success rate as function of country of previous education](image2.png)

Note though that the success rate of Swiss diplomas highly depends on the choice of options as seen in Figure 3: PAM students have roughly the same chances as holders of a European Scientific Baccalaureate with grade higher than 16/20.

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1 The small rebound in 2014 is ascribed to higher grade requirements imposed on European students.
So what exactly is going on in first year and what can be done to revert this tendency? An interesting outsider’s perspective is provided by gymnasium teachers working at EPFL in the framework of the MINT project. They are ideally positioned to observe how students adapt, or fail to adapt, to EPFL when they transition from Maturity. Below are excerpts sampled from MINT project reports and they paint a fairly coherent story:

« Par conséquent, un des premiers problèmes auxquels les étudiants sont confrontés est d’acquérir la capacité de remobiliser des savoirs qui datent parfois de 2-3 ans et de réussir à faire des liens entre ces savoirs. »

« … leur difficulté à s’organiser pour prendre des notes. Un exemple: s’ils ne connaissent pas la signification d’un mot, ils font des recherches sur internet sans se préoccuper du fait que le cours continue »

« les étudiants venant de suivre deux heures de cours n’ont pas le temps ni d’assimiler, ni de se poser des questions concernant ce cours »

Could it be that students produce less effort than their peers in other schools? All statistics point to the contrary, but a recent report of the Boston Consulting Group on higher education benchmarked the teaching models of 12 institutions spanning a large spectrum of educational models: NUS, DTU, Cambridge, UBC, GeorgiaTech, U. Toronto, U. Hong Kong, U. C. Berkeley, U. Melbourne, Minerva, ETHZ, EPFL. The comparison of class time in these institutions is particularly striking: In all these of them, students declare 55-75hrs working hours per week, but in 9 out of 12 institutions, students spend less than 15 hours a week in courses. For half of these institutions, students spend at least 50% percent of their work time on personal work and the tendency is to increase this amount. At EPFL, most students will follow roughly 30 hours a week of classes (regular courses and exercises/labs), spread over up to 9 different topics/semester. Personal work complements that, but there is no sign of this ratio tilting towards more personal work in the recent past, much to the contrary.

In parallel, EPFL faces a very specific challenge in first year: The Swiss Maturite provides access to EPFL, yet the topics covered in high school are very broad, resulting in a cohort of students with vastly different backgrounds. Swiss and residents with a maturity degree in Physics/Maths are the top performers in average and succeed in first year roughly equivalently to foreign students joining with Scientific Baccalaureate and grade higher than 16/20 (Fig. 3). We must organize our pedagogy by taking into account the very diverse background of students joining EPFL in first year such that everyone gets a fair chance without lowering our expectations.

The Task Force also discussed how we could better prepare students before the Polytechnic
Core. Indeed, faced with a plurality of students backgrounds, it is hard to make assumptions on their level in maths and physics. An interesting avenue could be to develop a set of online classes and tests that should prepare the students to join EPFL. The level of this material could follow the CMS or the new Mise à Niveau (MAN). Online tests could also serve has self-evaluation for incoming students. There are diverging opinions on whether self-evaluation has any impact of prospective students.

However, an interesting example is given by the Flemish engineering schools in Belgium: Twelve years ago, the Flemish government decided to abandon the mandatory admission tests to its engineering schools. The immediate result was a sharp increase in failure in first year engineering. The universities reacted by setting up optional Positioning Test\(^2\), whose aim is to help students assess their level of maths and physics. Students receive feedback after a week, including recommendations to either re-assess their choice of study or work on weaknesses. However, an incentive is provided: students who take the test receive 1 ECTS. A study found out the Positioning Test has excellent predictive value and helped reduce the failure rate.

Finally, students should develop at EPFL skills that should prepare them for the workplace. In a 1996 report entitled "Learning the treasure within", also known as the « Delors report », UNESCO paved the way for 21st century education. Like many other essays and treatises on education\(^3\) it emphasizes the increasing importance of learning through life and identifies two pillars of that concept:

- **Learning to know**: Given the rapid changes brought about by scientific progress and the new forms of economic and social activity, the emphasis has to be on combining a sufficiently broad general education with the possibility of in-depth work on a selected number of subjects. Such a general background provides, so to speak, the passport to lifelong education, in so far as it gives people a taste - but also lays the foundations for learning throughout life.

- **Learning to do**: In addition to learning to do a job of work, it should, more generally, entail the acquisition of a competence that enables people to deal with a variety of situations, often unforeseeable

A key skill is the ability to learn through life and that can only by accomplished by developing gradually a strong capacity for autonomous work habits. Due to the quantity of courses in first year, the amount of personal (i.e out of classroom) time a given student can devote to a particular topic was recognized by all as too small. For the same reason, it is challenging to apply any form of continuous control in first year, let alone to engage in new pedagogy relying on personal work (see Section 3).

\[^2\] These tests are free, non-binding and organized online based on MCQ.
Recommendation

The main objective of the Task Force was to enquire whether a pedagogical reform of the first year could help tackle these challenges. Pragmatically, the objectives of a potential reform are therefore twofold:

- Strengthen the acquisition of strong polytechnic foundations for all first year EPFL students, irrespective of their background and major orientation and
- Develop healthy work habits compatible with studying at EPFL while developing students’ personal work and autonomy.

Therefore, we believe that the key to unlocking a better learning experience lies in reducing the number of topics, while keeping a constant effort on the students’ side.

To estimate the effort a student should put on any given subject, we took the assumption of evenly balanced effort, based on students reporting to work approximately 55hrs/week. The **Task Force recommends that the number of courses in first year be around 5 per semester** yielding, in average, one full day per subject or roughly 11hrs per week including contact hours and personal work. Within the Bologna framework, this corresponds to 5 courses of 6 ECTS per semester, again to be understood as a moving target.

Moreover, the **Task Force recommends that 50% of the first year be devoted to the Polytechnic Core**. At present, this core includes 5 topics:

- Linear Algebra,
- Analysis I, II,
- Physics I, II.\(^4\)

In parallel to these foundational topics, each section would then be free to propose breadth courses for the remaining 50% of the study plan – again following the principle of restricting the total number of courses.

Clearly, focusing on key foundational subjects and few breadth courses will allow students to devote more time to each subject providing more flexibility for teachers to select the right balance between ex-cathedra, exercises. With only 5 courses per semester, it would also be easier to use continuous forms of control in first year and it is widely recognized that continuous control greatly contributes to better learning but also helps developing strong work habits.

It is interesting to note that strong foundations are not just important for students who will advance through educational cycles at EPFL, but also for those who fail in first year and quit EPFL:\(^5\):

- Where most students are successful in pursuing a second type of studies post-EPFL, the nature of these studies varies, yet the strong polytechnic core was praised as a strong foundation one can build on.
- Students mostly point at work habits when asked to single out the main reason for failing at EPFL.

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\(^4\) This list could be revisited as discussed in the next section.

\(^5\) Based on questionnaire responses in an EPFL study.
Strengthening the polytechnic core would also pedagogically complement other efforts invested by EPFL in the first year. As of spring 2017, students with weak grades on the current polytechnic block will be directed to a special semester focusing on maths, physics and work habits (MAN).

Finally, one must also face the reality that roughly 60% of EPFL students declare working part-time alongside their studies; some by choice, some purely to sustain themselves. A system offering more flexibility in study time, with less courses and more personal work would be beneficial.

The Task Force also discussed various propositions concerning Global Issues. The general consensus among members is to keep Global Issues in first year as a coefficient 2 course outside the polytechnic core.

**Recommendation 2: Revisit the Polytechnic Core**

**Background & Analysis**

Polytechnic disciplines are at the heart of our philosophy of education and this report proposes a model that strengthens these foundations. But much like any other part of our curricula they can and must evolve to follow major changes in science and technology. Opening up the Polytechnic Core to new disciplines, although natural, could nevertheless prove challenging or even counterproductive with respect to the main thrust of this document: increasing the amount of polytechnic courses would indeed gradually take us back to our starting point. In parallel, most if not all polytechnic courses are offered at different levels of depth (for instance mathematics are taught at an advanced level for mathematicians and physicists). Finally, we do not wish to negate the particularities of sections for it is also these particularities that form a vibrant and attractive curriculum.

In summary, when enlarging the Polytechnic Core, we should carefully reflect on what is truly part of this common basis and, if possible from an educational and organizational point of view, offer enough flexibility to sections.

Can we immediately identify topics that are ripe for inclusion in the Polytechnic Core? Did any discipline recently involve into a universal tool, one that should be taught early on to all EPFL students with enough breadth and depth?

Certainly one such change has been taking place over the last decade: the growing importance of computer science in every realm of science and technology. Often computer science is mistakenly interpreted as programming, which is a tool already taught very early on to students. By computer science we mean literally the exposure to algorithmic reasoning or computational thinking and ways to deal with problems involving data and computations. Interestingly other institutions have witnessed, and successfully coped with, this tendency. There is no denying the enormous importance of data processing in science and the emergence of Data Science as a key enabler for discovery in applied sciences. At Harvard for instance, CS50 – the introduction to computer science, is now the most attended freshman class. The Task Force believes it could be time to extend the Polytechnic Core to Computer Science so every new EPFL student gets a proper exposure to what is essentially a different way of thinking about computational problems, one that complements mathematics in rigor and physics in abstraction and modeling. The Task Force therefore recommends to mandate the IC Faculty to study the potential of reworking the
current ICC course to an Introduction to Computer Science, eventually formulated in two flavors (regular, advanced). We further recommend to engage with all sections and determine whether this course should be included in the overall Polytechnic Core for all sections or on-demand.

**Recommendation**

The Task Force suggests that a short list of 8 to 10 polytechnic classes could be proposed. Sections would give their feedback on which ones would be most interesting for their students. The outcome of that process could help design different scenarios for a future Polytechnic Core:

- « The lowest common denominator »: A fixed list of subjects, but at different depth levels. This is very much the current system at EPFL.
- « P out of N »: A broader list of courses tagged as polytechnic, inside which sections are allowed to choose a subset for their study plan.
- Requirement-based polytechnic block: sections announce minimal polytechnic requirements to offer their Major and students are then free to choose in which courses they enroll. This is the more « modular » approach, but also the most distant to our current practice and most challenging from a purely logistic point of view.

**Recommendation 3: Encourage (and empower!) pedagogical innovation and diversity**

**Background & Analysis**

There has been ample progress and research in the last few years showing that various models can be employed to increase student learning (see below). But most of these new models can only be used if students have enough time to work by themselves. Structuring the first year around a smaller set of courses, with more time available per course and for personal course, could therefore be an excellent opportunity to revisit pedagogy. Such initiatives should be encouraged but also empowered, as they require significant efforts to set up.

As an example, the « Candi 2000 » project at the Ecole Polytechnique de Louvain (UCL) is one such example – a large scale educational project that federated the entire faculty. In 2000, UCL decided to completely restructure its Bachelor cycle in engineering around a project-based approach. All students in first year receive the same project assignment, usually expressed in fairly abstract terms: « design a robot that will evacuate rubbles from a nuclear power plant after an incident ». Students work in small groups of 5 to 8 on a semester basis. Every week, is scheduled as follows. Each group meets at the beginning of the week with a Professor and coaches, they discuss the program for the week. Then students work typically 8 to 10 hours in groups. Then they meet with the same coaches at the end of the week to debrief. The first meeting structures the objectives, the second one focuses on learning outcomes and plans the work ahead. Projects are synchronised with traditional classes. There are only 17hrs/week regular classroom courses, mostly maths, physics and programming. When a particular concept is needed for the project, it is introduced in parallel in one of the regular class: the notion of trajectory, how to design a controller, how to solve a system of equations … Fifteen years of feedback collected by UCL show a sharp increase in learning using this approach.
Note though that the context at UCL is markedly different than at EPFL: there is a total of 1800 students in engineering for the whole undergrad (roughly our first year) and students entering engineering are pre-selected via a mandatory entrance exam. However, discussions with Professors who have been involved in designing and running the new curriculum shows that a major benefit of this approach is the “contextualisation of learning”: abstract concepts learned in maths and physics are better cemented when put into context via other disciplines or projects.

The last two decades has seen an enormous focus on research and development of pedagogical approaches in higher education. This has been motivated by a number of concerns about traditional university pedagogies:

- While students learn most when they are actively processing information, much of their timetabled time in universities is spent passively receiving information in lectures
- While there is a great deal of evidence about the value of low stakes assessment and immediate feedback on learning, university students often focus attention primarily on high stakes testing with little feedback
- Traditional teaching and pen-and-paper-based assessment has been found to give rise to students who can excel at solving abstract problems on paper but can struggle to articulate what their findings mean in real-life situations.

The recognition of these challenges has led to the development and evaluation of numerous innovative pedagogical practices, often grouped together under the title of “active learning” approaches. A recent meta-analysis of 225 studies of active and traditional learning in science and technology education has found convincing evidence that these approaches are more effective than traditional teaching in supporting student learning.

**Figure 4:** Active learning approaches give rise to increased attainment and reduction in failure rates across a range of science and technology subjects, as compared to traditional teaching. Note: Source: (Freeman et al., 2014, p. 8411). Each bar shows the average effect size and 95% CI. Numbers below the data points indicate the number of independents studies included in the analysis.
**Recommendation**

The task force recommends that upon implementation of the first two recommendations new forms of engaging the student with the topics are to be encouraged and empowered, centering on a number of different possibilities.

In this regard, EPFL is blessed with superb laboratory infrastructures that could be used more actively in the earlier phases of the curriculum. A central element is CAPE, who advises teachers and can also perform longitudinal studies to measure the effect of new pedagogies on student cohorts.

In the Annex, a number of case studies of “new pedagogies” are presented. A defining feature of these new pedagogies in science and engineering education is that they are evidence-informed and data driven. The pedagogies have been developed based upon an analysis of how students learn, and having been implemented, each one has been carefully evaluated to identify how what impacts it has in its given context.
Annex I: New Pedagogies in Practice

Feedback on learning in lectures: Immediate feedback has been found to play an important role in shaping learning. Without immediate feedback students may misunderstand lecture content, but may be unaware of their own misunderstanding (Laurillard, 2002). Various different techniques exist for teachers to ask questions of students during lectures in order to allow both students and teachers to gauge how well students understand the material. One common approach is the use of electronic audience response systems (“clickers”). Using clickers, the teacher asks a multiple choice-type question to assess student understanding of material which has been taught. Student responses are collected and a histogram of responses can be displayed. Where sufficiently large numbers answer incorrectly, the teacher may then re-explain the material, or may ask students to explain it to each other. This gives immediate feedback to students and teachers on how well students are understanding material, as well as providing an opportunity to correct misunderstandings. Clicker use has been found to increase student thinking about their own learning during lectures, (Brady, Seli, & Rosenthal, 2013), and have been found by multiple studies to contribute to an increase in student attainment on exams (e.g., Freeman et al., 2014; Mayer et al., 2009).

In EPFL, Clickers were used in 105 different courses with over 9,000 students in 2015.

Interactivity in learning: Student interaction with teachers and with each other in university classes have been found to be positively associated with increased learning (Blasco-Arcas, Buil, Hernández-Ortega, & Sese, 2013). Student interactivity can be achieved without the use of electronic devices, through the use of collaborative learning methodologies like ‘Jigsaw’.

Jigsaw is a variant of the “learning by teaching” approach which makes different students responsible for teaching part of that classes content to their peers. The Jigsaw activity is divided into two parts. In Part A, students are divided into groups and each group is assigned a different task (which might be to analyze a phenomenon or to understand a particular text). In part B, the groups are reconstituted with each group being made up of one member from each of the groups from part A. Each person is now responsible for teaching the new group about their own task, while the teacher is available to organize the activity and to help clarify problematic ideas or concepts. In this way, the whole material is covered by all students in an active and collaborative way. Part A can be conducted either before class by students (as homework) or in class.

The impact of the Jigsaw method in university-level engineering courses has been assessed and the data indicates that students perform better on material learned through the Jigsaw method than they do on material covered using traditional teaching. The data also shows that, despite some initial student resistance, the majority of students found that Jigsaw improved their learning (Maceiras, Cancela, Urréjola, & Sánchez, 2011).

The Jigsaw method is currently being used by a number of EPFL Professors.

Flipped classrooms: When students complete part A of the Jigsaw activity as homework before class, Jigsaw is an example of what is referred to as a “flipped class”. In traditional classes, students gather information when in class with the teacher and then struggle to process and understand this information later on their own. The guiding idea in flipped classroom is that it is better to have the teacher present when the students are actively processing and understanding information. Therefore the order of activities is flipped: students study the material before class (from a MOOC, a text or from on-line materials), then the time in class is taken up with tasks that enable students process and understand the information with the help of the teacher.
Numerous studies have found that flipped classrooms have positive effects on student learning in science and engineering, including studies in statistics, architecture, and chemistry (Herreid & Schiller, 2013).

The winners of the 2015 EPFL Credit Suisse Award for Best Teaching, Jamila Sam and Jean-Cédric Chappelier, use a flipped classroom for teaching in Computer and Communication Sciences. They have found that, in addition to students being more motivated, the flipped class has had a positive impact on attainment, with passing rates being 16% higher in 2014 when compared to the same test in 2007.

**Tangibles and simulations:** One of the challenges with university-based science and engineering classes is that students can struggle to relate abstract ideas and pen-and-paper calculations to real-life events and phenomena. This has led some observers to claim that “traditionally taught courses do little to improve students’ understanding of the central concepts of physics, even if the students successfully learn problem-solving algorithms” (Crouch & Mazur, 2001). One way of making the linkages between abstract concepts and real-life is through the use of in-class demonstrations, as well as hands-on investigations and virtual simulations.

While in-class demonstrations are a useful way of linking abstract ideas to everyday life, greater learning gains are typically seen in learning contexts in which students are actively engaged in enquiry and exploration (de Jong, Linn, & Zacharia, 2013). Due to the challenges of cost and accessibility, there has been a growing interest in the use of virtual labs and simulations in supporting student learning. In addition to allowing large numbers of students to access the simulation at the same time, without using (or damaging) expansive equipment, virtual simulations can also enhance conceptual understanding by allowing students to visualize otherwise invisible phenomena (see Figure 2).

As with other teaching and learning approaches, key to the use of virtual labs and simulations is that the simulation is not simply used by the teacher to demonstrate a phenomenon, but that the students are assigned laboratory tasks to engage with and explore the simulated reality. For example, Clark and Chaberlain required students to use the models of the hydrogen atom simulation (Figure 2) in a 60-90 minute lab task that was designed to enable students to understand the idea of modelling, to visualize different atomic models, and to engage students in inquiry-based science activities.

The University of Colorado PhET project has over 100 interactive simulations many of which are suitable for university science learning.

In EPFL, Remote Labs have been developed and evaluated by a number of teachers including Denis Gillet and Christophe Salzmann.
Figure 5: A screen shot of the PhET interactive simulation of models of hydrogen atom

Note: Source: (Clark & Chamberlain, 2014, p. 1199) The simulation allows exploration of six different atomic models (Bohr model is shown). In the simulation, photons are directed at a hydrogen atom, and students observe the resulting interactions, emission spectrum, and electronic transitions consistent with each model.

**Problem-based Learning:** While all of the models described so far in this section could be implemented by a given teacher in a specific class the concept of problem-based learning is different: while problem-based learning can be done as a class activity, it was originally conceived of as a design concept for an entire programme curriculum. In traditional curricula, projects often play an integrating ‘capstone’ role: after students have learned in different courses about different disciplines (chemistry, mathematics, physics, structures, materials, hydraulics, control systems, energy and so on) they then integrate their learning from these different courses by undertaking a project that requires them to draw on multiple disciplines. PBL curricula (Edström & Kolmos, 2014) typically begin with students being confronted with a problem to analyze and understand. Students analyze the problem together, supported by one or a number of tutors, and this then leads on to an identification of what the students know, and what they would need to know to address the problem. Student learning of ‘content’ is then related to the problem. It is typically done in an interdisciplinary way, with lectures then delivering the content that is relevant to the problem under discussion. Throughout the period, students continue to analyze the problem alongside their other classes, refine their learning goals and carry out the research they need to address their knowledge gaps in collaborative social groups.

Problem-based learning is used in a number of engineering programmes including those in Aalborg, Carnegie Mellon, and West Point. PBL has many similarities with the Conceive-Design-Implement-Operate (CDIO) curriculum model which was originally developed in MIT and is used in curriculum in numerous universities including Chalmers, KTH Royal Institute of Technology, and Linköping University (Edström & Kolmos, 2014). While there is some evidence that traditional models of engineering education may be more effective in terms of short-term retention of knowledge, PBL courses typically score higher
on long-term knowledge retention and application of knowledge to practice situations (Strobel & van Barneveld, 2009).

References


