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Joint Education for Advanced Chip Design in Europe (Edu4Chip)

Deliverable Report

The Program Concept

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Content

Abstract

The report describes the Edu4Chip program concept. The Edu4Chip program is a two-year Master program in Advanced Chip Design that is jointly designed and independently - but in an aligned form - offered by five top European universities, namely, TUM, DTU, IMT, TAU, and KTH. The program contains not only theoretical training but also intensive practical training with a focus on chip tape-out by students from front-end design, back-end design, manufacturing, to testing. It also has tight collaboration with leading semiconductor industries across Europe. The program encourages student exchanges among the five universities and supports flexible lifelong learning and open source. The report gives an overview of the program including the learning objectives, program structure and content, learning assessment criteria, student selection and exchange, and support for lifelong learning and open source.

Chapter 1. The Program Content

This chapter details the overall content of the Edu4Chip program. It starts with intended learning objectives, and then gives an overview of the program structure and courses, in particular, the chip tape-out centric project, and finally its learning assessment strategies.

1.1 Intended Learning Objectives

The chip shortage crisis has highlighted the importance of integrated circuits and systems, which are foundations for modern digitized countries. Along with the chip manufacturing crisis and the envisaged increase of the manufacturing capabilities in the chip sector in Europe, the shortage of skilled chip design engineers and talents is the biggest challenge to semiconductor industry growth in Europe and globally. Although almost all engineering universities offer microelectronics programs, the skill gap and shortage of chip designers continues to grow.

The Edu4Chip project is a joint effort by five top European universities, namely, TUM, DTU, IMT, TAU, and KTH, to collectively address the challenge. Currently, almost all microelectronic education programs base their training on theoretical lectures of chip design and practical lab modules, which either simulate the designed hardware or synthesize the hardware design on programmable devices, such as FPGAs. While modern chip design education requires a deep understanding of circuit technology, it also needs wide practical training. The Edu4Chip program brings such training to the next level by allowing students to design and tape-out their own chips during studies. This problem-oriented approach to chip design education will not only deepen the students' understanding of technology and circuit theory, but also allow them to gain hands-on experience at all stages of chip design.

The Edu4Chip project develops a two-year master-level program focused on chip design. It is offered by five top European universities independently but in an aligned form that encourages long-term collaboration of universities and exchange of students. A unique characteristic is that every student in the program will design and test a chip. It sets the intended learning objectives in three aspects: Knowledge and Understanding, Skills and Abilities, and Evaluation Capability, which each student is expected to achieve upon the completion of the program.

Knowledge and Understanding:

- be able to design, implement, and test a chip
- show knowledge and understanding of the processes, methods and tools used in the development of advanced chips
- demonstrate knowledge and understanding of current chip research and development and industry trends
- show knowledge and understanding of sustainable development, especially sustainability aspects related to chip products and services.

Skills and Abilities:

- demonstrate the ability to integrate knowledge through holistic thinking, identify, formulate and address complex problems in chip design
- be able to plan and develop relevant chip products within given time frames, and manage the process
- show ability to present and discuss technical problems, methods and solutions in chip design, both orally and in writing.

Evaluation capability

- be able to critically assess problems, methods and solutions in chip design with considerations of relevant sustainability aspects
- demonstrate the ability to give constructive opinions on problem formulations, methods and solutions in chip design
- show ability to identify the need for additional knowledge and skills, and follow future development trends in chip design.

1.2 Teaching and Learning Activities

1.2.1 Overall Structure

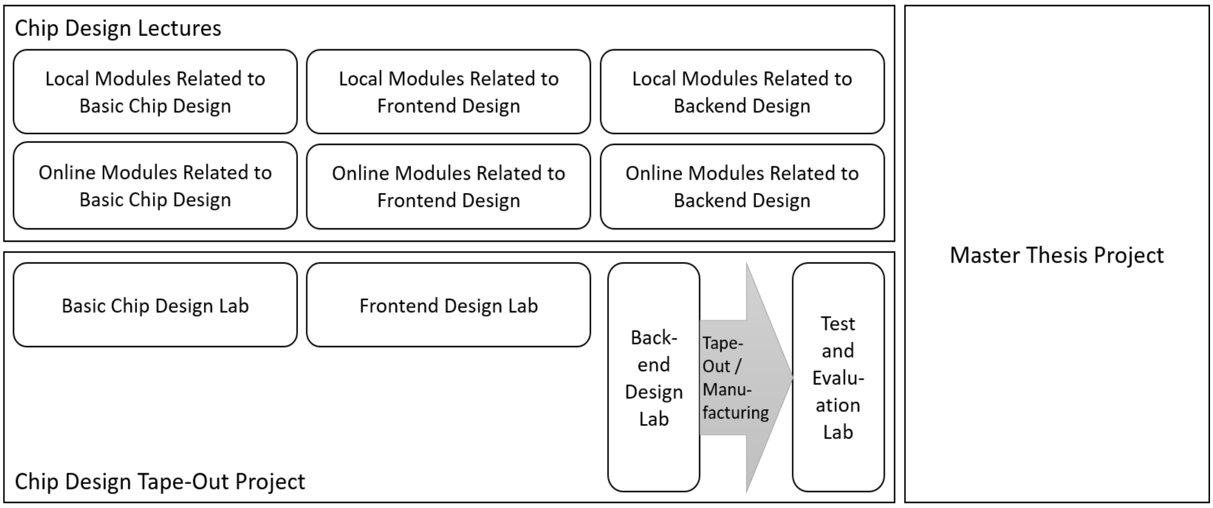

Figure 1. Overall structure of the two-year Edu4Chip master program

The overall structure of the study program is shown in Fig. 1. It is a four-semester program with one semester reserved for the preparation of a Master thesis. Two semesters constitute one study year. The workload per semester is usually 25 to 35 ECTS credits. The total number of credits is 120 credits (incl. Master thesis). The instruction language of the program is English.

The first semester focuses on basic skills in digital and analog design. The second semester includes more advance topics related in particular to the front-end design. For the third semester, it offers further specialized courses and courses related to the back-end design. The overall program consists of a more theoretical part with lectures from the domain of chip design (cf. Section 1.2.2) and a practical part in which students will do a tape-out (cf. Section 1.2.3). A Master thesis will conclude the study program, which can also be conducted in collaboration with industry.

The Master programs are aligned between university partners, to make exchange of students easy as detailed in Section 2.3. For this purpose, an exchange window is foreseen in the study programs. At most universities this will be in the second semester and students might decide to take the second and third semester abroad.

1.2.2 Courses

The program offers various courses across the entire chip design and test spectrum. For most partner universities, these courses are often organized as two types of courses: *compulsory or core modules* and *elective* courses. Compulsory courses are required to be taken by all students in the program; core modules define basic courses in chip design but allow the students with a degree of freedom. The elective courses allow students to select courses of their own interest. For most partner universities, the chip design project, which splits over the four semesters, is compulsory for all students who follow the Edu4Chip program. Each university may have specific requirements on other compulsory courses but selects these courses in order to provide students comprehensive knowledge in chip design. Students in the program might also take lectures around the topic of green IT and from the domain of social science to make students aware of sustainability goals and their social responsibility and to provide them means to reach related goals.

Moreover, the program accounts for external lecturing and supervision of master thesis projects, which will be related to the produced chips.

Also, the five universities aim to offer selected lectures in an online format, so that students have flexibility in choosing courses from partner universities. The partners aim to design corresponding courses and to set up corresponding contracts between the universities.

While the general framing described so far is the same for all partners, the detailed course list and arrangement differs between universities to be in line with the specific regulations and rules that apply in each country and at each university.

TUM plans to establish a new Master Program Microelectronics and Chip Design, which gives a large degree of freedom in elaborating the program. At TUM two focus areas can be chosen by students: they might specialize towards analog/mixed-signal or digital chip design (also a combination of courses from both branches is possible but recommended only in specific cases). To achieve this goal, students have to solve a chip design project from the respective domain in the lab part. With respect to courses, on the one hand students are encouraged to take elective courses (at the amount 30 credits, cf. Appendix A 1.3) that are related to their focus area. On the other hand, the requirements regarding the selection of core modules related to basic chip design are different depending on the students' focus: All students need to fetch 20 credits from two lists; one list related to analog/mixed-signal and one related to digital design (cf. Appendixes A 1.1 and A1.2). However, students should take 15 credits from the list of core modules in their focus area and 5 credits from the domain they do not focus on. The idea here is that both analog and digital designers should have some basic knowledge from the respective other domain. With 25 credits foreseen for the labs, 30 for the Master thesis, and 50 for mandatory and elective courses, the remaining 15 credits shall be fetched from one scientific seminar, at least one lecture from social or economic sciences, and one lecture from an application domain to broaden the education of the students and to improve their skills beyond chip design.

DTU will integrate the Edu4Chip initiative into the existing MSc program in "Computer Science and Engineering". To obtain a MSc degree in "Computer Science and Engineering", students are required to meet the following academic requirements: (1) Complete at least 10 ECTS from Polytechnical foundation courses, (2) a minimum of 50 ECTS from program-specific courses (Computer Science and Engineering), (3) undertake and successfully complete a Master's thesis project worth 30 ECTS within the scope of the general program. To reach the total of 120 ECTS needed for the degree, students must complete a sufficient number of elective courses. The Edu4Chip initiative is integrated into this flexible structure, primarily within the "Digital Systems" specialization. In specific, this means adapting a selection of existing courses to include Edu4Chip activities, as well as creating new and ad-hoc special courses (an ad-hoc special course is a single-iteration course created for students that desire to acquire a deeper and more research-oriented knowledge of a subject). However, students from any specialization within the Computer Science and Engineering program can participate in Edu4Chip courses. These courses can be selected as program-specific courses or as part of the elective component. We expect, but we cannot force, students to follow all the courses related to the "Digital

Systems” specialization. The same also applies to the chip design project, which splits over the four semesters: it will not be compulsory, but recommended.

For **IMT**, the master program of Edu4Chip targets the last two years of its ISMIN engineering program. Several tracks are offered to the students, about a quarter of the approx. 100 students, may join the Edu4Chip program. To qualify for the Edu4Chip program, the students will have to follow the Microelectronics major (MSc semester 3, 170h, 11 ECTS) and a dedicated ASIC design track (from semester 1 to 4 with several ASIC related projects covering the topic from the first design steps to an actual tape out).

A new post-master program on Microelectronics Circuit Design will be also created by IMT in line with the objectives of the Edu4Chip project. This one-year postgraduate program will be carried out on an apprenticeship basis. The compulsory academic courses represent a total of approximately 400 hours in our school (45 ECTS, 5 modules covering the whole topic of microelectronics design).

TAU will integrate the Edu4Chip initiative into the Master's Programme in Computing Sciences and Electrical Engineering in the form of specialization module Advanced Studies in System-on-Chip Design (80 credits). Students who select the module need to complete the compulsory list of digital design courses totaling to 30 credits and select 20 credits in focus areas of computer engineering, digital design, or analog design. Master's thesis is 30 credits and included in the module. The remaining 40 credits in the Master program consist of joint mandatory studies and elective courses.

KTH will implement the Edu4Chip program in its international Master program “Embedded Systems”. It is a two-year program with 120 credits. The Embedded Systems program has been operated and continuously developed for more than ten years. Currently it has three specialization tracks, namely, Embedded Electronics, Embedded Platforms, and Embedded Software. All three tracks are linked to Edu4Chip at different levels. The Embedded Electronics track focuses on both analog and digital circuit designs. The Embedded Platforms track mainly deals with large-scale digital systems such as CMPs, ASICs and FPGAs. The Embedded Software track emphasizes the software running on embedded processors, in particular, applications with real-time constraints. Basic chip design courses are already part of the Embedded Systems program. The chip design tap-out project will be a capstone project course (or split into a few small courses) for the students who are interested in Edu4Chip to select.

The preliminary list of main courses offered by the five participating universities can be found in Appendix A. The courses have credits listed. We note that, while the European Credit Transfer System (ECTS) applies to all university partners, the rules how one ECTS credit can be earned and the granularity at which the credits are allocated slightly differs between universities. This will be considered in the mutual approval of academic achievements gained by students at partner universities.

1.2.3 Chip Design Tape-Out Project

Different from other current microelectronics programs in Europe, our program emphasizes that every student completing the study programs participated in all steps of the chip design flow. Thus, the core of the program is the chip design project, which spans the entire study years. It consists of four specific lab tasks (the credits and concrete partitioning are indicative and can deviate for some partner universities):

- As a first part (5 credits) a preparatory course for chip design and associated lab tasks is given.
- The second part (10 credits) requires students to work on a front-end design.
- The third part (5 credits) is the back-end design including physical design.
- The fourth part (5 credits) is the test and evaluation, after the chip is manufactured.

As previously mentioned, the chip design project is compulsory for all students who follow the Edu4Chip program for all partner universities except DTU, where it is only recommended. The aim of the first part of the lab is to provide the base for subsequent efforts where students shall work independently in groups of 3 to 8 people. In the second part, students will work on a project in chip design. They will start with an abstract description of the task and will have to do the front-end part of the design until a gate-or transistor-level description. The students shall continue their work (possibly in the same group) during the third semester where they will do the back-end part of the design, starting with the design from the previous part, and follow the design flow until they have a placed and routed design that follows the design rules for the selected technology from which the GDSII data for the tape-out can be generated. In the last part of the lab, students will bring a chip in operation and do experiments depending on the design they implemented.

To enable the tape-out project, common tool chains will be set up, and a joint baseline chip will be prepared and maintained before student tape-out. This joint effort will foster the long-term collaboration between the partners. The IP blocks designed by the students will be embedded into the chip template.

While the framing of the tape-out project is fixed, and all partners depend on the same baseline chip, it allows also for the flexibility needed to implement the program in the different settings and under the different rules and constraints that apply to universities in different European countries. In particular, it allows for time flexibility when the different parts of the program are implemented in the curriculum, for variations in the group size, and for different applications that can be designed by the students, without negative effect on the main intended learning outcome that is to enable students to be practically capable to master all steps in a chip design.

The specific arrangements at partner universities in the framing of the Common Chip Design Project are described as follows.

Within the framing of the described chip design project, **TUM** plans to offer two main directions: Students can specialize in digital design and implement a design from an application domain such as AI acceleration or design for security, or they can specialize in direction of analog/mixed-signal design with a project such as design of a PLL. In any case students will be challenged with a high-level specification and constraints they have to fulfill. It is planned that students do the project in groups of approx. 5 students and they will get trained along the first part of the chip design with respect to group work and project planning. To be in line with the rules that foresee that the last semester is exclusively dedicated for the master thesis, the plan is to have the back-end part of the design at the beginning of the third semester and the test and evaluation part at the end of the third semester.

At **DTU**, our chip design projects will emphasize digital design across various applications, including real-time systems (e.g. using our T-CREST platform), general-purpose computing, and hardware acceleration. Computer architecture for real-time and general-purpose systems may include the implementation of processors, interconnection fabrics, and peripherals. Hardware acceleration applications may include the development of custom solutions for tasks like machine learning and video processing. Each tape-out project will concentrate on a specific example within these areas.

At **IMT**, the chip design project will focus mainly on digital design. Students will follow a dedicated ASIC-design track that takes them through the main steps of an ASIC design. Starting from a high level specification, they will design their own student IP from HDL modeling through the front-end and back-end steps, up to the tape-out. The ASIC-design track will be taught in groups of 4-5 students through different projects during the semesters of their curriculum (semester 1: HDL description and validation, semester 2: front-end, semester 3: back-end + tape-out, semester 4: test of the fabricated ASIC).

Student projects will mainly focus on hardware security, hardware acceleration, and processor implementation with an emphasis on RISC-V architectures (other topics can also be chosen). ECTS for the ASIC-design track will be granted according to the program of the ISMIN diploma.

IMT will also run a post-Master program (a French Master spécialisé). The duration of this program, one year on an apprenticeship basis, will not correspond to the 2-year schedule of the Edu4Chip Chip design tape-out project. However, IMT will implement a similarly tailored Chip design tape-out project with the same objective: to design an integrated circuit from HDL description, to an actual fabrication and test. To this end, the students will enroll in the Tiny Tapeout initiative (https://tinytapeout.com), or in a similar open-silicon initiative that makes it possible to design and embed their own digital IP in a test chip to be fabricated.

TAU will focus on digital design in the chip design project. The front-end design phase in the second semester is divided to two courses, one on design and one on verification. The courses are 5 credits each and run in parallel. The design course will focus on System-on-Chip integration process and related issues using an example IP the students develop and validate during the semester. The verification course will support the project with verification methods. The complete system is prototyped on FPGA, and later implemented on ASIC in the back-end course in third semester. The wake-up lab will be implemented after the first successful tape-out. The example IP can include existing open-source hardware and the application can vary between implementations. Possible application areas for the IP include real-time RISC-V architectures, video encoding accelerators, and security subsystems.

At **KTH**, one specialization track in embedded electronics, valid from 2025, focuses on System-on-Chip design. During the first semester, the students have four 7.5 ECTS compulsory courses, covering VLSI design, digital RTL to GDS (front-end and back-end) flows, and Analog integrated circuits. With this background, the students start an ASIC project course of 30 ECTS during the second semester. This project-based course consists of designing an application-specific integrated circuit (ASIC) covering all steps from specifications to submission of GDSII fabrication masks (tape out). The designs will be sent for fabrication at the end of the second semester, and their performance will be measured in another course in the program at the end of the third semester. Students will work in small groups of 4-5 people. The course involves strong interaction with industrial partners, who will provide suitable topics for the projects, supervision, and design reviews during the course.

1.2.4 Close Collaboration with Industry

The program has close collaboration with leading industrial partners in the semiconductor field across Europe. These industrial partners are fully engaged, not only in giving advices but also in developing the content of the program. Some courses (in part or in full) will be offered by industrial experts, to allow students to access the most recent state of the practice in the field. The companies will offer internship and master thesis projects, give guidance to students working in relevant projects. Furthermore, top experts from top semiconductor companies will be invited to give lectures on special selected topics in courses and associated summer schools.

1.3 Assessment

1.3.1 Grading System

Each partner university uses its own grading system that is dictated by the respective government. Nevertheless, all universities have well established rules to transfer from one grading system into another one. This is common practice, e.g., in the Erasmus+ program and will be applied in this program, too.

TUM uses 1-5 scale grading system with steps 1.0, 1.3, 1.7, 2.0,..., 5.0. Grade 4.0 is the last pass. Everything larger is a fail. In addition, some modules are graded on a pass/non-pass basis.

DTU uses the Danish grading system that employs a 7-point scale to assess student performance. The grades are as follows: 12 (Excellent), 10 (Very good), 7 (Good), 4 (Fair), 02 (Adequate), 00 (Inadequate), and -3 (Unacceptable). Note that 00 and -3 are not passing grades. Additionally, some courses are graded on a pass/non-pass basis, rather than using the numeric scale.

IMT uses a 0-20 scale grading system. A mark of 10/20 (or above) is required to pass a course. Courses are grouped into modules (2-3 different courses on a similar topic), and a lower mark result can be compensated by a higher mark in another course from the same module (the average grade for the module must be at least 10/20, in any case the course will be failed if the mark is lower than 08/20).

TAU uses the Finnish 0-5 grading scale. Grade 0 is failed, close to European Credit Transfer and Accumulation System (ECTS) grade F, and 5 is excellent, close to ECTS grade A. Additionally, some courses are graded on a pass/non-pass basis, rather than using the numeric scale.

KTH uses the ECTS grading system. The grading system for courses follow either a two-level grade scheme: Pass or Fail, or a letter-based seven-level grading scheme: A (Excellent), B (Very good), C (Good), D (Satisfactory), E (Sufficient or Acceptable), Fx (To Complete), F (Failure), where A to E mean pass with A being the highest grade, and F the lowest meaning failure. Fx (To complete) means that student will have an additional examination chance to pass the course to reach grade E.

The conversion from one grading system to another grading system upon credit transfer will use each university's standard conversion table.

1.3.2 Grading criteria

The grading criterion is based on the assessment of fulfilling the intended learning objectives for each course or the entire program. This means that the grading is not based on relative performance in comparison with other students.

Chapter 2. Program Accreditation, Student Selection and Exchange

Chapter 2 first describes the accreditation of the joint program at participating universities. It then details issues about student selection and student exchange. The shared curriculum promotes easy mobility between the academic partners.

2.1 Program Accreditation

The Edu4Chip master program will be accredited in all partner universities before it is put into operation. The way of accreditation may vary from university to university, depending on which the best way is to incorporate the program.

For **TUM**, it is planned to establish a new chip design master program in line with the Edu4Chip program. In such a program, students shall receive a Master of Science in Microelectronics and Chip Design. The program shall start in October 2025. The master program concept is constructed around the practical tape-out project, which is a core element of the program. Two focus areas are planned: Digital Design and Analog/Mixed-Signal Design from which students can select their focus area. Since the program is a new master program, it will go through the regular accreditation process and needs to pass all legal compliance checks.

TUM plans to complete the application stage of the program in late 2024 and to open the application portal for students in spring 2025, so that the until then accredited new master program can start in October 2025.

For **IMT**, a new post-master program will be created in line with the objectives of the Edu4Chip project. It will be a one-year diploma, a French “Master Spécialisé” (MS, or Specialized Master), on Microelectronics Circuit Design. This one-year postgraduate program will be delivered on an apprenticeship basis. It will be open to MSc graduate students. Students will follow their academic courses while being employed by a company at the same time. The academic courses represent a total of approximately 400 hours in our school (15 full weeks), the remaining time is dedicated to gaining industrial experience in the field of microelectronics at their company. The MS courses follow the main organization of the Edu4chip master program: it focuses on chip design and includes the design and testing of an integrated circuit by the students. A key aim of this program is to attract MSc students and give them the opportunity to specialize in microelectronics to contribute to ease the shortage of skilled chip designers. This new post-master program will go through accreditation in 2024-2025 to open in October 2025.

For IMT, the master program of Edu4Chip will be also partially integrated into the courses of one of its engineering programs: the ISMIN – Master’s Degree in Microelectronics and Computer Science from Mines Saint-Etienne (French engineering diploma). ISMIN is a three-year engineering program, with the development of microelectronics courses through Edu4Chip targeting the last two years. It has several elective courses, of which the Microelectronics major is the most relevant. The ISMIN curriculum undergoes a regular re-accreditation process.

Other three universities have no intention to establish a new master program for Edu4Chip, but integrate the program into their existing programs already accredited and undergoing the regular accreditation process.

For **DTU**, the Edu4Chip program will be integrated into the existing “Computer Science and Engineering” MSc program, mainly within the “Digital Systems” specialization by adapting a selection of existing courses to include Edu4Chip activities, as well as creating new and ad-hoc special courses. However, any student enrolled in the “Computer Science and Engineering” program can take courses offered under the Edu4Chip program, regardless of their chosen specialization. At DTU, specializations are merely suggestions, and students have the flexibility to select any course that aligns with their interests and career goals.

For **TAU**, the Edu4Chip program will be integrated into the international Master's Programme in Computing Sciences and Electrical Engineering. An advanced study module of System-on-Chip Design will follow the Edu4Chip curriculum.

For **KTH**, the Edu4Chip program will integrally operate in a closely related international master program, namely, the Embedded Systems master program. A subset of students in the Embedded Systems master program will be selected to follow the Edu4Chip program curriculum. Currently the Embedded Systems program has three specialization tracks: Embedded Electronics, Embedded Platform, Embedded Software. Students in the Embedded Electronics and Embedded Platform tracks are more suitable candidates for the Edu4Chip program.

2.2 Student Eligibility and Selection

To ensure the quality of the Edu4Chip program, it is important to admit candidates with sufficient background to join the program. Luckily all five participating universities are well known and attract excellent students worldwide.

The prerequisites (admission conditions) in language proficiency and major-related knowledge & skills for entering the Edu4Chip program will be clarified.

TUM will require a corresponding certificate or to prove sufficient language proficiency by a Bachelor thesis written in English. TUM will have admission rules that require a Bachelor in a topic where specific skills are proven in the domains such as math, electronics, programming, etc. with sufficient grades as well as a motivation letter. Export control concerns will be handled on a university level. Students using commercial tools will have to agree corresponding NDAs or License Agreements.

At **DTU**, the selection for the “Computer Science and Engineering” MSc program, where Edu4Chip is implemented, is conducted in accordance with current university regulations. Admission requirements include a BSc degree (or equivalent) in a relevant field, showcasing specific skills in mathematics, electronics, programming, and related areas. In addition, applicants need to provide a certificate to demonstrate sufficient language proficiency (or demonstrate it by other means).

IMT students join the ISMIN curriculum (Master’s Degree in Microelectronics and Computer Science from Mines Saint-Etienne, a French engineering diploma) after succeeding to an engineering school national entrance exam. It is a selective exam following two years of preparatory classes. Students joining the Edu4Chip program will do so after their first year (corresponding to a Bachelor’s degree).

Selection for IMT’s Specialized post-Master program on Microelectronics Circuit Design will be open to MSc students on the basis of their academic record and curriculum. They will be required to find a host company for their apprenticeship.

At **TAU**, the general eligibility requirements are applicable Bachelor's degree and good command of the English language for academic purposes. The Bachelor’s degree should be from a closely related field with proficiency in mathematics and physics, and elementary programming skills. The English language proficiency can be demonstrated with previous studies or a language test. In addition to the general requirements, basic knowledge of electronics, digital logic, processors, computer architecture, and programming is expected of the students applying to the System-on-Chip specialization that implements the Edu4Chip program.

For **KTH**, the student selection for the Edu4Chip program will be conducted in two steps. The first step is the general admission to KTH Embedded Systems master program. Students will have to meet the general entry requirements including English proficiency and fulfill the program-specific requirements in order to be eligible for the Embedded Systems master programs. Eligible applicants with higher merit values will be admitted. The second step is the Edu4Chip program selection. Students admitted to the Embedded Systems master program are not necessarily becoming a student of the Edu4Chip program. The Edu4Chip program will be open to all students in the Embedded Systems master program. But only those students who express interest and have right background will follow the Edu4Chip program.

2.3 Student Exchange

2.3.1 Exchange Agreement

Student exchange agreements will be established between partner universities, either at the school level or at the university level. To allow full mobility among partner universities, each pair of universities shall work towards establishing a student exchange agreement, if no such agreements exist before. In total, we plan to have 10 exchange agreements in effect. Any exchange-related legal issues should be clarified in the exchange agreements.

2.3.2 Forms of Exchange

The forms of exchange will not only include physical exchange but also virtual exchange. For some students, it may have both physical exchange and virtual exchange elements, forming a blended exchange.

- Physical exchange: It is time-limited, usually one semester long exchange in a partner university. An individual exchange study plan, which includes equivalent or new courses and credits to be studied, needs to be approved by the outgoing university.
- Virtual exchange: It is course based. A student may select courses from partner universities after receiving approval from his/her home university program. Virtual exchange means remote participation in courses. This option can be open for a subset of program courses. Courses which require physical participation, e.g., for labs, are not suitable for virtual exchange. We note that, at this moment, the possibility of virtual exchanges is not certain, since the partner universities are in the process to verify the legal requirements for such an option.

The mobility will include both students and teachers and will be implemented by means of the Erasmus+ project. Additional mobility scholarships can enrich the exchange for students receiving no grant.

2.3.3 Practices of Student Exchange

The implementation of student exchange may be different from university to university. In the following, the current practices about student exchange such as course selection and credit transfer at partner universities are described briefly.

TUM: Students participating in the Erasmus exchange program, apply at TUM for a place at their targeted partner university. With this application, they provide a preliminary list of courses they plan to attend. During a semester abroad, they need to yield currently at least 10 credits. The choice of lectures at the host university has to follow dedicated rules and students can request a transfer of the credits from a host university back into the TUM grading scheme. TUM has a central exchange office which cares for setting up contracts and decentralized exchange offices on school level, which take care of the applications, credit recognition procedure, etc.

DTU: For students participating in an exchange program at DTU, it is required to first select the courses offered by the host institution prior to departure. The selected courses are entered into a form, which is then approved by the student’s program director. Upon successful completion of the courses at the host university, the credits will be recognized and transferred to DTU's academic record system. DTU has a central exchange office which manages all aspects of the exchange process together with the student’s program director.

IMT: At IMT this is still to be decided and it has to be clarified how the exchange of ECTS credits can be done, unless it is a full semester at a partner’s MSc. In the latter case, students will have to select courses at a partner university and obtain the approval of a referee professor. Once validated by the host university, the ECTS credits will be transferred to our curriculum.

TAU: Students who apply for exchange at TAU have a two-stage selection process. In the first stage, students can list multiple destination options in their application, and they need to provide a preliminary study plan with at least 30 credits per semester for each exchange destination they apply to. TAU international coordinators select the successful applicants and inform the host universities of the selections. In the second stage, the pre-selected students send their applications to the host university. Credits earned while on exchange will be recognized and transferred to the TAU degree by inclusion or substitution. The transfer of credits is decided in the degree program.

KTH: For students in an exchange program, they will need to complete an individual study plan with course selection before going to their exchange university for study. The students select courses from the exchange university and fill in the course selection form. The individual form needs to be approved by the student’s program director. After completing the courses at the hosting university, the courses will be recognized and transferred to KTH’s study record system. KTH has an exchange office at each school, which handles all exchange-related issues from start to end.

Chapter 3. Support for Lifelong Learning and Open Source

Chapter 3 first describes how the Edu4Chip program facilitates lifelong learning for chip designers across Europe. Then it outlines planned summer schools and details its open-source activities. These educational efforts are aligned with the long-term European vision of developing an independent and sustainable chip design and manufacturing economy.

3.1 Course Catalog for Lifelong Learning

The possibility of joining the program as regular-semester students and selecting lifelong learning modules as vocational students will be offered. To make our program easy access for chip-design engineers not in the regular master programs, it will implement a series of life-long learning courses by adapting lectures and courses developed for the MSc programs alongside new content. In particular, a course catalog as a lifelong learning module will be compiled as part of the Edu4Chip program materials.

The courses offered as life-long learning modules will be mainly special-topic courses, which target specialized advanced design questions, like the design of circuits for hardware security or specialized hardware architectures for AI algorithms. Such courses are especially relevant for persons who are already in industry or have already some background in chip design and wish to advance their skills. In the course catalog, prerequisites will be clarified, so that the minimum background is clarified for chip design practitioners.

The currently planned lifelong learning courses are listed in the following table. It can be further renewed and modified according to the interests and needs of industry along the execution of the Edu4Chip program.

Course name	**Offering university**
Innovative Computing for AI	TUM
Agile hardware design with alternative HDL languages (e.g. Chisel)	DTU
Chip design using open-source tools	DTU
Hardware security, Fault injection attacks (theory + labs)	IMT
Hardware security, Side channel analysis (theory + labs)	IMT
FPGA digital circuit design flow (courses + labs)	IMT
IC manufacturing: fabrication of a MOS capacitor	IMT
SoC Verification	TAU
Electronic Systems Design	KTH

Table 1. Course catalog for lifelong learning

3.2 Offering of Lifelong Learning

The lifelong learning courses will be offered on-site, either in the form of intensive-teaching courses or regular courses. Intensive teaching courses are organized case by case, usually taking one to two weeks. This often means additional efforts to customize a course in content and structure for the needs of companies and vocational students. In the form of regular course offering, vocational students take the courses just as regular students in the study program.

To allow study at any time anywhere, selected teaching materials will be made available for off-line access. Some course materials will be offered online using the universities' dedicated platforms and the Digital Skills and Jobs Platform.

The lifelong learning courses may be offered with or without credits. This means both students in the regular study programs and industrial engineers can take the courses at the same time. This can be particularly good in terms of creating an excellent peer-learning environment because of possible interactions between students and experienced engineers in the same classroom.

3.3 Administrative Support for Lifelong Learning

To admit students outside universities to the Edu4Chip program, each university will follow its local university policy. A contract may need to be established when admitting an external student to the Edu4Chip courses. Tuition fee may incur, depending on national/university regulations. Such a contract is necessary in order for a university to register an external student, give access to course materials, attend labs, submit labs and assignments, and take examination. After successful completion, a certification of attendance can be awarded to the life-long participants by the universities providing the course.

3.4 Summer Schools

The Edu4Chip project will organize three summer schools. These summer schools will invite industrial keynote speakers, and meanwhile, welcome engineers from semiconductor industry to attend. The lectures in the summer schools will cover latest chip design and development trends, which are not usually covered in other courses.

3.5 Open Source

For a selection of the courses included in the Edu4Chip programs, we will prepare and share the learning materials including lectures, reading material, projects/exercises, and reference materials in the form of slides, texts, videos, and code.

Our program intends to promote the study of integrated circuit design through the actual design and fabrication of an IC by students as part of their curriculum. This chip will follow a common template and will embed IP blocks designed by the students. Some of these IPs might be designed and released as open source. If feasible by law, a public open source repository (possibly hosted on GitHub or by one of the partner universities) is to be created to offer a selection of the produced technical materials, tools, and IPs to other educators.

Sharing the aforementioned materials with the public enables access to advanced educational resources in chip design, fostering a collaborative learning environment across institutions. It will significantly contribute to the innovation and growth in the microelectronics industry in Europe and globally.

Chapter 4. Summary

The report has detailed the Edu4Chip program concept, which is a two-year master program in microelectronics designed jointly by five top European universities. Besides theoretical fundamentals, the program weighs heavily on functioning skills in the entire chip design and test flow, which student in the program will practice in a chip design capstone project. The jointly designed program has strong collaboration with leading semiconductor industrial partners across Europe.

The report has defined the program's learning objectives in knowledge and understanding, skills and abilities, as well as evaluation capability. The program is structured in four semesters. The workload per semester is usually 25 to 35 ECTS credits. In total, it is 120 ECTS credits. Compulsory and elective courses are listed, showing sufficient details about the content of the program. The grading system follows ECTS, and the assessment of learning outcomes will be aligned with the intended learning outcomes, rather than relatively to peer students' performance.

To implement the program across the participating universities, the report has also described how the universities will accredit the program, either plans to open up a brand-new program or integrating the program into their existing chip related master programs. Students will be admitted or selected to the Edu4Chip-related programs according to local universities' requirements and criteria. As a key element of the cross-university collaboration in education, student exchange agreements (if not already in place) are planned either at the university or the school level, facilitating student mobility in the Edu4Chip program. Finally, the report has described its ambition in supporting lifelong learning to train vocational students, along with its open source activities if legally permissible.

The Edu4Chip program serves as a blueprint for other universities who wish to join the initiative and to offer an aligned program in chip design that is open for exchange and lifelong learning in the future.

Appendix A: Lists of Main Courses Offered by Participating Universities

A.1 Preliminary Course List of TUM

This section provides a preliminary list of courses that shall be offered at TUM within the new Master Program Microelectronics and Chip Design. Students have to fetch 20 credits (15+5 or 5+15) from the list of compulsory courses (A.1.1 and A.1.2) and 30 credits from the list of elective courses (A.1.3)

A.1.1 TUM - Core Modules Analog/Mixed-Signal Design

- Analog and Mixed-Signal Circuit Design; 5 credits
- Micro-structured Devices in Micro- and Power electronics; 5 credits
- Analog Bipolar Electronics; 5 credits
- Fundamentals of CMOS Technology for Analog Design and Standard Cell Libraries (1); 5 credits

A.1.2 TUM - Core Modules Digital Design

- HW/SW Codesign; 5 credits
- Testing Digital Circuits; 5 credits
- Electronic Design Automation; 5 credits
- Design of Digital Circuits; 5 credits
- Logic Synthesis and Physical Design; 5 credits
- Memory Technologies for Data Storage; 5 credits

A.1.3 TUM - Elective Courses

- System Design for the Internet of Things; 5 credits
- System-on-Chip Technologies; 3 credits
- Multi-Criteria Optimization and Decision Analysis for Embedded Systems Design; 5 credits
- Mixed Integer Programming and Graph Algorithms for Engineering Problems; 5 credits
- Phase Locked Loop/Clocked Circuits; 4 credits
- System Design for High-Frequency and High Data-rate Applications; 6 credits
- Advanced Cryptographic Implementations; 5 credits
- Quantum Computers and Quantum Secure Communications; 5 credits
- Embedded Systems and Security; 5 credits
- Circuit Design for Security; 5 credits
- Embedded System Design for Machine Learning; 6 credits
- Innovative Computing for AI; 6 credits
- Chip Multicore Processors; 6 credits
- CMOS Analog-to-Digital Converters; 5 credits
- Circuit Reliability for AI in Advanced Technologies; 6 credits
- Fundamentals of CMOS Technology for Analog Design and Standard Cell Libraries (2); 5 credits
- Machine Learning for Design Automation; 5 credits
- Software for Quantum Computing; 5 credits
- Physical Unclonable Functions; 5 credits
- Software Architecture for Distributed Embedded Systems; 5 credits
- Nanosystems; 5 credits

A.2 Course List of DTU

At DTU, all courses are elective since specializations serve as recommendations rather than strict pathways, allowing students the freedom to choose courses that best match their personal interests and professional aspirations. The courses directly related to the Edu4Chip initiative are:

- 02203 - Design of digital systems (5 credits)
- 02205 - VLSI design (5 credits)
- 02211 - Research topics in computer architecture (5 credits)
- 02209 - Test of digital systems (5 credits)
- 02201 - Agile hardware design (5 credits)
- TBD - Verification of digital systems (5 credits)
- 02118 - Introduction to chip design (5 credits)
- 02155 - Computer architecture and engineering (5 credits)

Other offered courses that relate to hardware and chip design topics, but not directly into the Edu4Chip initiative at the moment are:

- 34655 - Integrated analog electronics 2 (5 credits)
- 34656 - Design and layout of integrated CMOS circuits (5 credits)
- 34657 - System-level integrated circuit design (10 credits)
- 02214 - Hardware/software codesign (5 credits)

A.3 Course List of IMT

At IMT, the Master's degree courses are mostly elective, allowing students to tailor their studies in Electronics, Embedded Systems and Computer Science to their professional goals. The following courses are compulsory for participation in the Edu4Chip program.

- Electronic systems (semester 1, 5 credits, 66h)
  - Computer architecture
  - Digital system design
  - Introduction to cryptography
- Microelectronics Design - Microelectronics Basics (semester 3, 6 credits)
  - Analog circuit design introduction
  - Digital circuit design
  - Manufacturing processes & characterization methods
  - Modeling & characterization for semiconductor devices
  - Semiconductor devices
  - Semiconductor physics
  - Advanced simulation and verification
- Microelectronics Design - Design Methodologies (semester 3, 5 credits)
  - Advanced analog circuit design
  - Application specific circuit design
  - Co-design & prototyping
  - Processor architecture
  - HDL modeling & synthesis

IMT also offers elective courses in the field of Security, Electronics and Energy, Information Technology and Supply Chain, or Bio-Medical Devices.

A.4 Course List of TAU

Compulsory courses

- COMP.CE.200 Digital Design, 5 credits
- COMP.CE.240 Logic Synthesis, 5 credits
- COMP.CE.250 System-on-Chip Design, 5 credits
- COMP.CE.400 System Design, 5 credits
- COMP.CE.420 System-on-Chip Verification, 5 credits
- COMP.CE.510 Chip Implementation, 5 credits

Elective courses: Choose 20 credits

- COMP.CE.130 Computer Architecture, 5 credits
- COMP.CE.320 High-level Synthesis, 5 credits
- COMP.CE.340 Dependable Embedded Systems, 5 credits
- COMP.CE.350 Parallel Computing, 5 credits
- COMP.CE.460 Embedded Linux Drivers, 5 credits
- EE.ELE.475 Analog CMOS Integrated Circuits, 5 credits
- EE.ELE.485 RF and Mixed-Signal Integrated Circuits, 5 credits
- EE.ELE.495 Digital Integrated Circuits, 5 credits

A.5 Course List of KTH

The main courses listed here are extracted from the current Embedded Systems Master program. Old courses may be upgraded or replaced, and new courses may be developed and made available for the Edu4Chip program.

- IL2240 Semiconductor Devices for Integrated Circuits, 7.5 credits
- IH2653 Simulation of Semiconductor Devices, 7.5 credits
- IL2234 Digital Systems Design and Verification using Hardware Description Languages. 9.0 credits
- IL2225 Embedded Hardware Design in ASIC and FPGA, 7.5 credits
- IL2237 Electronic Systems Design, 7.5 credits
- IS2202 Computer Systems Architecture, 7.5 credits
- ID2218 Design of Fault-tolerant Systems, 7.5 credits
- IL2206 Embedded Systems, 7.5 credits
- IL2212 Embedded Software, 7.5 credits
- II2211 Research Methodology and Scientific Writing for Embedded Systems, 7.5 credits