

# Development of a competence ecosystem for the future space workforce: strategies, practices and recommendations from international master programs in northern Sweden

Victoria Barabash<sup>\*</sup>, Mathias Milz, Thomas Kuhn, Rene Laufer

Luleå University of Technology, Department of Computer Science, Electrical and Space Engineering, Division of Space Technology, Box 848, SE-981 28, Kiruna, Sweden

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## ABSTRACT

Requirements from the global labor market have substantially changed in recent years. Graduate and post-graduate students with excellent subject knowledge, deep understanding of modern working methods, technical and higher-order thinking, engineering intuition and problem-solving skills are in great demand. They should also have professional skills such as well-developed abilities in communication and teamwork, usually in an international work environment. This review discusses the advantages of multidisciplinary study environment, educational strategies such as student-oriented teaching, project-based learning with its applicability to a “real-world” setting, active learning techniques, development of entrepreneurial skills, lessons learned and best practices from the international Master Program in Spacecraft Design and the Joint Master Program in Space Science and Technology – SpaceMaster at Luleå University of Technology in northern Sweden. The importance of complementarity between formal, informal and non-formal learning methods for science and engineering students has been specifically highlighted. Connections to the world of work, through active industry involvement in the education in a systematic way, e.g. External Advisory Board, shared services and facilities, joint projects and supervision of Master and PhD students, is recognised as a key success factor for professional training. A structural combination of modern pedagogical tools, strategic partnership with industry, business entities, academic partners and up-to-date multidisciplinary labs creates the conceptual framework for a Competence Ecosystem for fostering a new generation of space scientists and engineers.

## 1. Sweden’s Arctic and space university

Luleå University of Technology (LTU) is Sweden’s northernmost university with its Space Campus in Kiruna [1]. Space and atmospheric research in northern Sweden has been closely connected to the town Kiruna located 140 km North of the Arctic Circle. The town is also well known for its iron ore mine LKAB and the world famous Jukkasjärvi Icehotel. The university has a strong Arctic profile with many years of education, research and business, related to the Arctic, in areas of civil and energy engineering, mining- and natural resources engineering, medical and health sciences, atmospheric and space sciences, and space technology. Research and development projects are done in interdisciplinary constellations in order to both effectively handle current and future global challenges, as well as to ensure a sustainable growth of economic activities in the Arctic region, where the role and importance of space activities has been particularly outlined by the European

Council in November 2019 [2].

Higher education and research in Sweden are under regulations, that are set up by the Ministry of Education and Research. The mission of the national universities is to offer education based on academic footing and proven experience, to undertake research and development work, and to cooperate with the surrounding communities. Universities are entitled to issue first, second and third-cycle general qualifications. The Swedish National Agency for Higher Education grants the permissions to the universities to award the specific qualifications and controls the program quality. Thus, accreditation of the educational programs in the country is done by the governmental authorities. LTU is a public-sector university and is subject to these legislations.

Space education at LTU started in autumn 1997 with the five year national Master (civilingenjör) Program in Space Engineering, 300 ECTS [3]. It has two specializations: (1) Spacecrafts and Instrumentation and (2) Space and Atmospheric Physics. The specialization Spacecrafts and Instrumentation has a clear system perspective. The students learn about

<sup>\*</sup> Corresponding author.

E-mail address: [victoria.barabash@ltu.se](mailto:victoria.barabash@ltu.se) (V. Barabash).

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**Acronyms/abbreviations**

BEXUS	Balloon Experiment for University Students
CDIO	Conceiving – Designing – Implementing – Operating
CNES	Center National D'études Spatiales, French Space Agency
DLR	Deutsches Zentrum für Luft-und Raumfahrt, German Aerospace Center
EACEA	Education, Audiovisual and Culture Executive Agency
ESA	European Space Agency
ESA-BIC	European Space Agency – Business

**Incubator**

LKAB	Luossavaara-Kiirunavaara Limited Company
LTU	Luleå University of Technology
IRF	Swedish Institute of Space Physics
PERSEUS	Projet Étudiant de Recherche Spatiale Européen Universitaire et Scientifique
REXUS	Rocket Experiment for University Students
SNSA	Swedish National Space Agency
SSC	Swedish Space Corporation

satellite design, control and communication. They exercise to plan and construct instrumentation for satellites, sounding rockets or high-altitude balloons. The specialization Space and Atmospheric Physics is focusing on space plasma physics and the Earth's atmosphere, with a particular interest in the polar atmosphere including space weather and climate change. The program has always been popular, and during the last five years, it has had the highest number of applicants among all of LTU's Masters programs.

Following EACEA's Call for Erasmus Mundus Master programs in 2004, LTU took an initiative to organise and coordinate a new joint two year Erasmus Mundus Master Program in Space Science and Technology – SpaceMaster [4]. The SpaceMaster has started as a consortium of six European universities and, after successful 16 years, it is now functioning as an international Joint Master Program with five European partners:

- Aalto University School of Electrical Engineering (Aalto);
- Cranfield University (CU), United Kingdom;
- Czech Technical University in Prague (CTU), Czech Republic;
- Luleå University of Technology (LTU), Sweden;
- Université Toulouse III - Paul Sabatier (UT3), France.

The SpaceMaster Program has three main objectives:

- offering the combination of the great diversity of space expertise at European partner universities to a common platform of competence within the guidelines of the Bologna process;
- providing cross-disciplinary knowledge and practical experience with balloons, rockets and small satellites;
- bringing together students from all over the world to share the existing space competence and benefiting the world space industry and research community.

The SpaceMaster is a four-semester Master Program, 120 ECTS. It has a common first year for all students that takes place at LTU's Kiruna Space Campus. During the third semester, the students are distributed among the partner universities, which have different fields of expertise in space science and technology. The students select the track of specialization during the application process with deadline in mid-January of every year. The different specializations cover almost all branches within space education. That creates the opportunity for

exchange of professional research and teaching experience for the academic staff between the universities and thus, to improve the quality of education on offer. There are five engineering tracks and three scientific tracks. The engineering tracks are:

- Space Robotics and Automation, Aalto University School of Electrical Engineering;
- Dynamics and Control of Systems and Structures, Cranfield University;
- Space Automation and Control, Czech Technical University in Prague;
- Space Technology and Instrumentation, Luleå University of Technology;
- Space Technique and Instrumentation, Université Toulouse III - Paul Sabatier.

The scientific tracks are:

- Atmospheric and Space Science, Luleå University of Technology;
- Astrophysics, Space Science and Planetology, Université Toulouse III - Paul Sabatier;
- Space Science and Technology, Aalto University School of Electrical Engineering.

During the fourth semester, students perform their Master thesis projects at the partner universities, industry or space agencies. They are supervised and examined by academics from two of the partner universities. This leads to two officially recognised Master's degrees issued by LTU and one partner university. The degrees are given below in English and the respective national languages:

- Aalto University School of Electrical Engineering: Master of Science (Technology), Diplomi-insinöörin tutkinto;
- Cranfield University: MSc Astronautics and Space Engineering (SpaceMaster);
- Czech Technical University in Prague: Degree of Master of Science, Study program Cybernetics and Robotics, Inženýr, studijní program Kybernetika a robotika;
- Luleå University of Technology: Degree of Master of Science, Major in Space Technology, Teknologie masterexamen, huvudområde rymdteknik;
- Université Toulouse III - Paul Sabatier: Master Astrophysics, Space and Planet Sciences, Master Astrophysique, Sciences de l'Espace, Planétologie; Master Space Technology and Instrumentation, Master Techniques Spatiales et Instrumentation.

Through its different editions, the SpaceMaster collaborated with universities outside the European Union, e.g. Shanghai Jiao Tong University (China), Stanford University (United States), the University of Tokyo (Japan), the University of Toronto (Canada), Utah State University (United States), and received financial support from the Directorate of Human Spaceflight and Operations of European Space Agency (ESA).

The SpaceMaster has more than 550 SpaceMaster alumni around the world. In September 2021, the Program started its 17th student intake. The Program main advantages can be summarized as:

- structured cooperation between academic institutions and industry;
- the education is influenced by current advances in research;
- increased intercultural understanding, positive attitudes and integration;
- structured cooperation between the universities via the use of the ECTS system, combining together different educational models;
- exchange of experience for both the academic and administrative staff;
- a wide range of specializations within one program improves the career prospects of students;

- positive impact on societies in the locations involved;
- cooperation between countries within and outside the European Union to promote the European space industries throughout the world.

The international Master program in Spacecraft Design, which has been started in 2012 with a focus on the continuing development in space industry towards smaller satellites, with shorter lead times and increased employment of commercially available subsystems, thereby opening up for a more entrepreneurial approach. In order to speed up the learning process, the working method of concurrent engineering is adopted to the design process. The main part of the modules in the program during the first year is studied together with the fourth-year students from the national Master Program in Space Engineering. The marginal cost for the program is therefore, optimized.

## 2. Competence ecosystem

The new Strategic Framework for Education and Training 2030 [5], approved by the Council of the European Union in February 2021, set up five strategic priorities for education and training:

- improving quality, equity, inclusion and success for all in education and training;
- making lifelong learning and mobility a reality for all;
- enhancing competences and motivation in the education profession;
- reinforcing European higher education;
- supporting the green and digital transitions in and through education and training.

These priorities, together with the recent trends of the global labor market force to continuous reviewing and rethinking of teaching and learning, imply special requirements on the educational sector. Graduate and post-graduate students are required to have excellent subject knowledge, deep understanding of modern working methods, technical and higher-order thinking, engineering intuition and problem-solving skills. Modern space projects involve solving complex professional challenges and demand a global perspective – requiring not only academic expertise, but often experience in a broad international cooperation. This includes understanding of intergroup contacts that shape and promote positive attitudes in a social context and therefore, increase effectiveness. That requires well-developed abilities in communication and teamwork. These multi-sided requirements can be met only through the Competence Ecosystem that is formed by different actors with different roles, but who share a common vision, and engage in collaboration. The conceptual framework for a Competence Ecosystem for effective implementation of national and international master programs in space science and technology at LTU is composed of five blocks (Fig. 1): educational programs and alliances, university research, academic partners, space agencies and organizations, industrial and business partners.

To be competitive, attractive and sustainable educational programs, particularly on the Master and PhD levels, shall be based on cutting-edge research that also foresees active collaboration within various types of alliances. The SpaceMaster Program described above together with Erasmus + Mobility are good examples of such very successful educational collaborations. Other examples are the newly established UNIVERSEH Consortium [6], LTU's Graduate Schools in Space Technology [7] and Creaternity [8]. These alliances implement a holistic approach and are based on a broad variety of the involved research subjects, which not only create a solid basis for interdisciplinary collaboration, but also facilitate a system thinking. University research multidisciplinary includes different areas of engineering, human and social sciences, economy and business, cultural studies, innovation and entrepreneurship. In order to develop this multidisciplinary environment as well as to create and strengthen the interdisciplinary

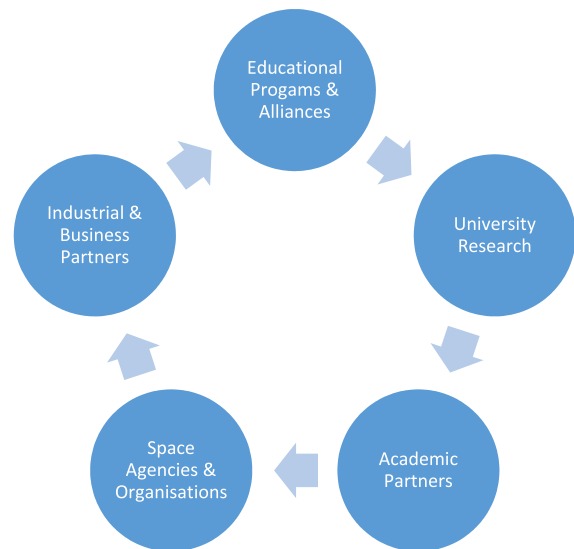


Fig. 1. University competence ecosystem.

interactions, the educators need to follow the latest trends in the world of work, to cooperate with the academic institutions, to interact regularly with the space agencies, and to establish a strategic partnership with industry and business entities. Connections to the world of work, through active industry involvement in the education in a systematic way, was recognised as a key success factor for professional training of engineering students.

Two external academic partners, the Swedish Institute of Space Physics (IRF) [9] and EISCAT Scientific Association [10], are located in the closest geographical proximity to the university at the Kiruna Space Campus. The former one carries out fundamental research and observatory activities in space plasma physics, space technology and atmospheric physics. The latter one conducts research on the upper polar atmosphere and ionosphere using incoherent scatter radars. Both partners actively participate in the educational process in different ways and create favorable conditions not only for formal or intended learning, but also for complementary informal and non-formal learning.

Being in high-latitude location and having a strong Arctic agenda, the university established broad interdisciplinary collaborations such as the Arctic Five with Umeå University, the Arctic University of Norway, the University of Lapland and the University of Oulu [11]. Kvarken Space Center is a regional project for development of a space ecosystem in Sweden and Finland [12] with the goals to raise a regional space technology awareness, ensure space education on different levels and to boost space related business.

Regular interactions with the European, national and international space agencies, European Commission via the Education, Audiovisual and Culture Executive Agency (EACEA) as well as with the International Academy of Astronautics improve exchange of information and strengthen ties between the educators and students on one side and space experts and policy makers on the other side. Strategic partnership with industry and business, e.g. SSC, OHB Sweden, ISAR Aerospace, Aerospace Cluster Sweden, ESA-BIC, not only intensifies joint projects with active student involvement, but also substantially facilitates updating of student's personal professional learning networks, that is considered to be a very effective pedagogical tool.

## 3. Multidisciplinary learning environment

The international Master programs at Kiruna Space Campus are embedded into the multidisciplinary research environment with modern labs and advanced test facilities, e.g. atmospheric and planetary sciences, space systems and nano satellites, spacecraft avionics, space

propulsion, Center of Excellence in Space Technology, regional development project “Space for Innovation and Growth” – RIT (Fig. 2). This environment allows students to learn not only within particular disciplines, but to learn interdisciplinary concepts in systems and progressively develop system thinking that is a cornerstone in system engineering.

#### 4. Design of program curriculum

The educational process is represented as stairs with three steps, i.e. from the learner via the contributor to the performer (Fig. 3). The learner is a student who can make use of university resources and has responsibility for her/his own learning. The contributor enriches the activities and tasks with her/his own knowledge, skills and experiences and make use of them for own development in collaboration with others. The performer shows high professional competence through actions. According to the revised Bloom's taxonomy [13] in order to achieve the effective learning, it is very important to ensure a smooth progression from the lower order thinking



Fig. 2. Multidisciplinary environment.

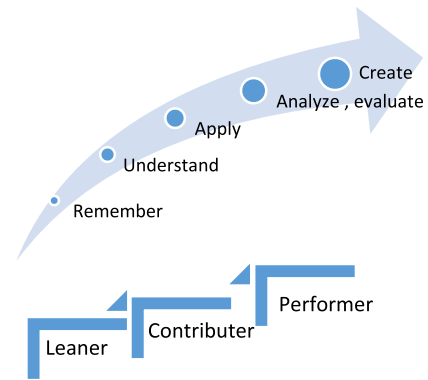


Fig. 3. Educational stages and learning progress.

skills to the higher ones via integration of the intended cognitive process, i. e. remember-understand-apply-analyze-evaluate-create, with the knowledge including factual, conceptual, procedural and metacognitive forms. Research based and student-oriented teaching in combination with project-based learning, hands-on experience, implementation of active learning techniques and Conceiving – Designing – Implementing - Operating (CDIO) initiatives appear to provide effective pedagogical tools for obtaining the mentioned above qualifications.

After successful completion of the Master program, the graduating student should have a changed self-image and the qualifications according to the Swedish Ministry of Education and Research:

Knowledge and Understanding.

- within the main field, i.e. space science and technology, with considerably deeper knowledge within certain parts of the field, that give deep insight into current research and development work;
- to show deep knowledge of methods within the main field of the program.

Proficiency Skills and Capacity.

- that demonstrate the capability to critically and systematically integrate knowledge, to analyze, evaluate and handle complex phenomena, problems and situations even with limited information;
- to critically, independently and in a creative way identify and formulate problems, to be able to plan and with adequate methods to carry out qualified tasks within the given time frames, and thus to contribute to the knowledge development as well as to evaluate this work;
- to make oral and written presentations during national and international events, to discuss problems and use arguments suitable for dialogs with different target groups;
- for participation in research and development work or for independent work in another qualified area.

Evaluation Skills and Viewpoint.

- to make evaluations with regard to the relevant scientific, social and ethical aspects for research and development work;
- to show scientific possibilities and limits, their roles in society and humanity's responsibility for the way of their use;
- to identify own needs for further knowledge and to take the responsibility for their own lifelong learning.

The graduates should also have professional skills in the form of well-developed abilities for communication and teamwork, usually in the international environment. These requirements can be met through project-based learning as a complementary teaching process [14–16]. Project-based learning aims at deep learning, the ability to apply



acquired understanding to new problems and situations, and a range of competencies related to human interaction and self-management [17]. It can promote a positive learning environment that strengthens constructive and effective relationships between students and teachers. Boyd and Hipkins [18] explained that learning is meaningful when the problems addressed are relevant to students and the “real world.” In addition to the goal of increased content knowledge and application, project-based learning promotes a positive learning environment and relationships between students and teachers [19]. The modern space projects involve complex professional issues, a global perspective and are very costly. In addition to academic knowledge, they require broad international cooperation. Human interactions become one of the success factors for such projects. That is why, it is necessary for space students to learn how to work in an international environment. This includes understanding of intergroup contacts that shape and promote positive attitudes in a social context [20–22]. These qualifications should be trained within the framework for formal education. However, this is a necessary, but not a sufficient condition, i.e. the learning interactions should be stretched outside the classroom. So, there is a need to integrate the formal learning with the informal and non-formal forms (Fig. 4). The importance of complementarity between formal, informal and non-formal learning has been widely discussed in recent years. The students should be immersed in vibrant and absolutely free-choice science and technology environment. Learning is meaningful when the problems addressed are relevant to students and the “real-world”. In this respect, the geographical proximity and strategic partnership with the academic organizations, industry and business entities become crucial. The students can participate in the research seminars and workshops for the senior researchers and engineers, international student competitions and challenges, national and international conferences and events. University business entities, e.g. LTU Business AB, organise schools and educational events in innovation and entrepreneurship. It is also important to integrate the internships into the program curriculum via, for example, a compulsory Master thesis of 30 ECTS (duration 6–8 months) and special study courses of 7.5 ECTS (duration of two months).

## 5. Student projects

One of the effective ways for active implementation of the problem-based learning is participation in the long-term student projects with nanosatellites, balloons and rockets. An excellent example is the European Space Agency’s (ESA) student projects using sounding rockets, REXUS, and stratospheric balloons, BEXUS, that allow students from European universities to carry out scientific and technology experiments. These two programmes are realised under an agreement between the German Aerospace Center (DLR), Swedish National Space Agency (SNSA) and ESA. Experts from international space organizations provide technical and administrative support to the student teams throughout the project, so the students experience communicating with external professionals to define and discuss the project requirements.

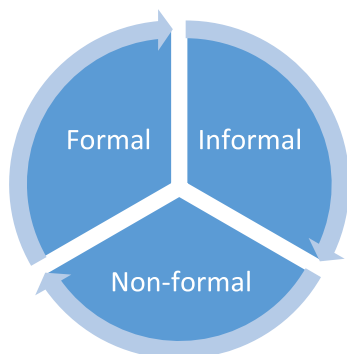


Fig. 4. Types of education.

Additionally, the students make a business trip to the Netherlands and Germany and experience the working culture outside their home university. Project duration is 16 months for the balloon experiments and 24 months for the rocket experiments. Each project cycle begins with a call for proposals for experiments, followed by a condensed space project lifecycle, including typical design phases and reviews, the launch of the experiments and publication of the final reports (Fig. 5).

These projects are integrated in the Master program curriculum with 15 ECTS points and are optional. We analysed eight student teams with 144 students, who participated in the projects between 2015 and 2020. Participating students came from two international and one national Master programs. The proportion of international students in the project groups varied between 35% and 50%, of which approximately 30% are from countries outside of the European Union. The proportion of participating female students varied between 13% and 44% for different project groups (Fig. 6). Some students participated in the projects voluntarily, without course registration and grades, i.e. totally following their own curiosity and high motivation.

The project originated from the student idea and was driven by the student initiative. This important condition substantially increased student motivation and united the project participants (Fig. 7). Joint responsibility for project success and collaboration within the group created positive attitudes, leading to the substantial improvement of the psychosocial environment within the group and well-being of individuals.

The project participants had diverse cultural and ethnical backgrounds, social norms, cultural sensitivity and learning styles. This circumstance stressed the importance of the staff knowing their students and their needs. Cultural awareness and sensitivity affect not only the way information is delivered, but also how the students are able to internalize this information. Clear rules and guidance from the staff, welcoming culture and active intergroup contacts supported the student’s project management and substantially improved the working environment, which was a prerequisite for good study results and satisfaction with the project and thus, the education as a whole. From our study, both positive and negative effects were reported due to a high level of peer-pressure. An individual had to adapt to project requirements that could lead to stress and conflicts. The stress was primarily related to the time constraints and eventual deficits in subject knowledge together with absence of necessary professional skills. Conflicts were mostly related to variability in learning styles and working cultures, divergence between personal preferences and project goals, as well as alternative views on project implementation. However, since the project arrangement was very close to the “real world”, the students were very motivated, and personal adaptation was usually quite smoothly. The students showed increased working efficiency and individual performance. They received very high grades despite their studies of other courses in parallel with the projects.

## 6. Strategic partnership with the world of work

The Master thesis project performed outside the home university is a student’s additional important step towards professional life. That is why, our university teachers encourage the Master students to perform

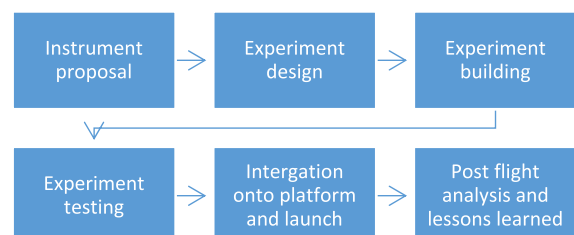


Fig. 5. Student project phases.

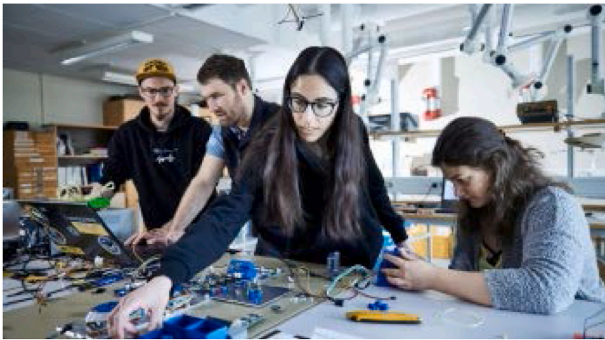


Fig. 6. REXUS 30 - team ASTER (Attitude STabilized free falling ExpeRiment) at LTU Project Lab.

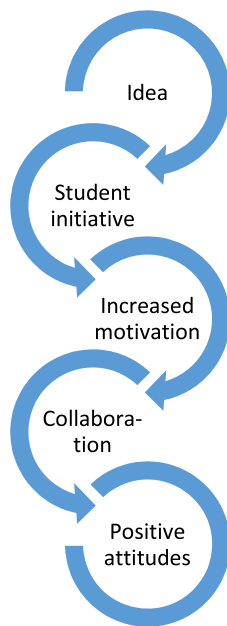


Fig. 7. Towards creative working environment.

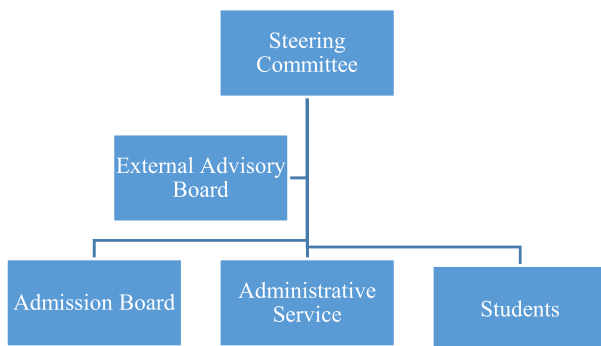


Fig. 8. Program management structure and the External Advisory Board.

the projects outside their home universities. The SpaceMaster students, since the program start, performed their projects at academic institutions, space agencies and space companies mainly in Europe, but also around the world. Airbus, Boeing, CNES, DLR, ESTEC-ESA, ESC Aerospace, GOMspace, Honeywell, ICEYE, IRAP, IRF, OHB, ONERA, SSC, Thales Alenia Space – these companies and organizations took care of the program students for more than 15 years. However, strategic

partnerships have been limited to the companies and organizations whose vision, values and interests match the educational goals. Clear and open communication, clarity of objectives and trust together with commitments at all levels were key success factors for such a collaboration. It was beneficial for companies, e.g. to have a work force with tailored competences and complementary skill set, for the university, e.g. facilitation of start-ups and increased positive impact on the society, and for the student, e.g. increased employability (92%) and expanded lifelong professional networks.

The agenda for strategic partnership included student scholarships, shared services and facilities, joint research and development projects, joint supervision of Master and PhD students, structural participation in the formal education, e.g. lectures and study visits. From the SpaceMaster experience, the most effective way to cooperate with the industrial partners was the creation of the External Advisory Board that supported the Master program faculty directors and consortium steering committee (Fig. 8).

The Board has been continuously working with the program quality assurance. It also provided the socio-economic, scientific and market information in order to guarantee the development of graduate profiles. The board members received a formal status of the associated partners that was legally confirmed by the memorandum of understanding, jointly signed by the organization and the coordinating university.

## 7. Conclusions

The presented Competence Ecosystem for space science and technology has been found to be an effective and sustainable tool for fostering a new generation of competent space work force who is capable to achieve strategic objectives of the European Union's new space programme, to address the global challenges and to promote the New Space agenda.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors acknowledge financial support from the Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology.

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