Chalmers University of Technology: Overcoming Resistance and Inertia in Education through the Dynamics of a Matrix Organization Including

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Chalmers University of Technology: Overcoming Resistance and Inertia in Education through the Dynamics of a Matrix Organization Including Student Co-Creation

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ABSTRACT

In this contribution we describe and reflect on the organization of Chalmers University of Technology and how it benefits education development and innovation. Chalmer's matrix organization with a buyer-supplier management model for education has proven to be a driving force for change and quality enhancement and promotes the agility necessary for implementing educational reforms in response to both internal and external impulses. We exemplify this by describing and analyzing development projects in curriculum design, education for sustainable development, entrepreneurship, and a new transformative model for flexible education.

Key words: Education Management, Engineering Curriculum, Institutional Change.

INTRODUCTION TO CHALMERS UNIVERSITY OF TECHNOLOGY

At Chalmers University of Technology (hereafter "Chalmers"), research and education in engineering, science, shipping, architecture and learning are conducted within our vision "Chalmers - For a sustainable future". Chalmers has around 10,000 full-time students (BSc and MSc), 1,000 PhD-students and 3,000 employees of which approximately 2,000 are faculty [1]. Chalmers has been a private university since 1994, with the Chalmers University of Technology Foundation as sole owner. Operations are regulated in a long-term agreement with the Swedish state, supplemented with annual agreements covering the upcoming year. Education for students from countries in the European Union (EU), European Economic Area (EEA) and Switzerland is financed by the Swedish government while students joining Chalmers from other countries pay tuition fees.

The Chalmers University of Technology Foundation manages the founding capital, and the return of the founding capital is used to fund strategic investments. Daily operations are covered by state funds, external research contracts and - to a smaller extent - tuition fees. The private ownership form - which is rare in the Swedish higher education system - gives the university the mandate to design its internal organization and support structures. In contrast to state universities which are led by governing bodies, Chalmers is governed through line management, meaning that it is led by individuals who are responsible for making decisions, supported by advisory bodies such as councils, committees and boards. The decision-making mandate is delegated top-down in "lines", such as the department line organizing the faculty and the education organization, organizing the Educational Areas (Schools) and programs.

Since 2005, Chalmers is organized as a matrix organization consisting of thirteen disciplinary departments organizing the faculty, a cross-departmental education management organization divided into five Educational Areas (Schools) responsible for managing and developing education programs, and seven interdisciplinary Areas of Advance as platforms for strategic and long-term research and innovation (Figure 1). The education management organization is independent from

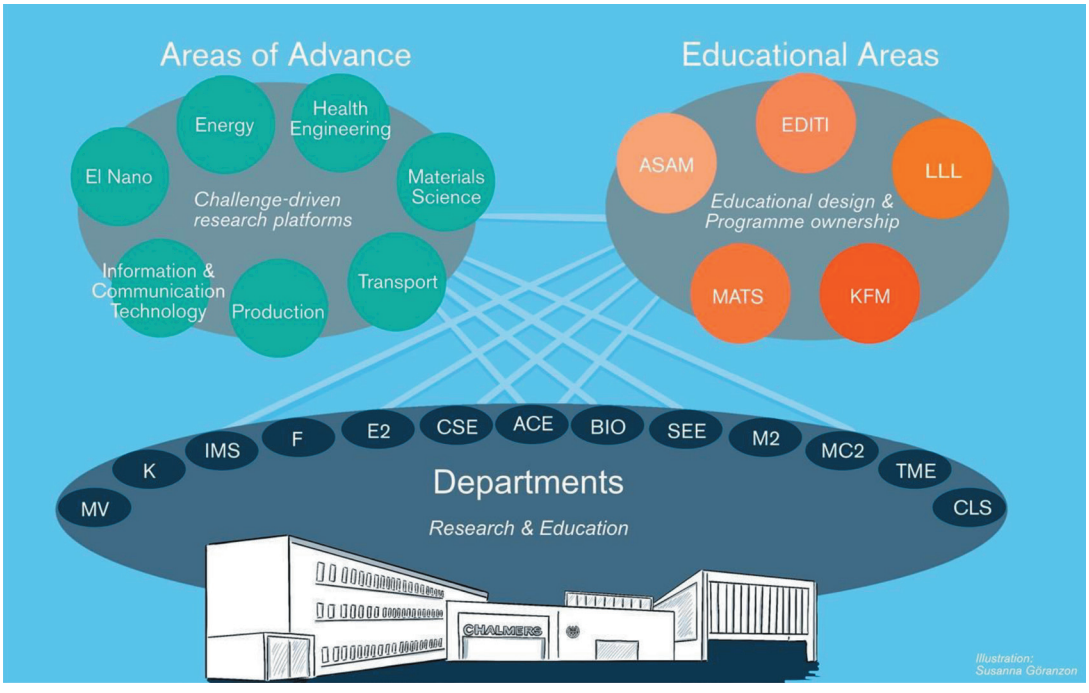

Figure 1. Chalmers' matrix organization consisting of Departments conducting research and education, Areas of Advance as platforms for challenge-driven research in specific areas, and Educational Areas (Schools) for design and management of education programs. Table 1 expands the acronyms of the Departments and Educational Areas.

Table 1. Departments and Educational Areas at Chalmers University of Technology.

Department acronym	Department name	Educational Area acronym	Educational Area name
ACE	Architecture and Civil Engineering	**ASAM**	Architecture and Civil Engineering
BIO	Biology and Biological Engineering	**EDITI**	Electrical, Computer, Software, and Industrial engineering
CLS	Communication and Learning in Science	**LLL**	Life-long Learning
CSE	Computer Science and Engineering	**KFM**	Physics, Chemistry and Biological Engineering along with Mathematics and Engineering Preparatory Year
E2	Electrical Engineering	**MATS**	Mechanical Engineering, Mechatronics and Automation, Industrial Design Engineering, and Shipping and Marine Engineering
F	Physics		
IMS	Industrial and Material Sciences		
K	Chemistry and Chemical Engineering		
M2	Mechanics and Maritime Sciences		
MC2	Microtechnology and Nanoscience		
MV	Mathematical Sciences		
SEE	Space, Earth, and Environment		
TME	Technology Management and Economics		

the departments where the faculty are organized according to discipline and do their primary tasks of research and teaching. The Areas of Advance are research platforms gathering researchers from different departments around thematic, challenge-driven research problems. The Educational Areas (Schools) design education programs and engage teachers from all departments in its courses, allowing for program design independent of departmental faculty composition. The staff of the Educational Areas consist of the management/administration roles of Dean of Education, Head of Program and Director of Master's program, to which faculty members apply in competition. In that role, they work for the Educational Area rather than for the department where they have their main employment. Deans of Education are responsible for appointments for most positions, and Deans of Education are in turn appointed by the Vice-President for Education and Life-Long Learning. Each appointment process starts by setting up an appointment committee with representatives from the Educational Areas and the Student Union. They support the person responsible for the appointment in selecting and interviewing suitable candidates and serve as advisors in the appointment decision. Each appointment is made for periods of three years, which may be extended to a total of nine years after satisfactory performance evaluation.

Students at Chalmers are organized by the Chalmers Students' Union and are represented in university governing bodies at all management levels, from department management bodies and education program management boards to university and owner foundation management boards. The student union represents all students at the university and membership is mandatory for students. Mandatory membership gives the student union a financial situation allowing for their governing body to employ students for core functions on a yearly basis, giving stability in their management and operations. The fact that students are organized in one single organization creates one counterpart for the university in all matters concerning students. Mandatory membership has contributed to strengthening the role of students and the student union at Chalmers, ensuring that students can safeguard their personal and collective rights and that the education meets student needs and expectations both in quality and content.

As previously mentioned, program education at Chalmers is organized in Educational Areas (Schools) responsible for the management and development of education programs at bachelor's and master's level. A buyer-supplier model is used between Educational Areas and the departments. Each Educational Area is led by a Dean of Education, responsible for setting the overall strategy and coordinating the development of the programs of the schools. The Deans are members of the Executive Committee for Education lead by the Vice-President of Education and Life-Long Learning. The Executive Committee of Education outlines university-wide strategies and guidelines and follows up on implementation.

The Heads of Program composes program curricula by purchasing courses from different departments. The remuneration to departments is based mainly on the size and level of the course, but factors in also teacher engagement and the pedagogical scope of the course. The Heads of Program commissions courses from the delivering departments in an annual agreement process. In the agreement, content, pedagogy, and extra budget for development to be made during the upcoming year are specified. Departments can suggest new courses and offer to take over courses from other departments in this annual process. In addition, Heads of Program can open courses for tenders when need for reform has been identified. If no department is able or willing to deliver according to a tender, the terms can be renegotiated, or the course can be commissioned from another university.

The major advantage of the buyer-supplier organization is that it ensures that the (by nature multidisciplinary) education programs are well composed and unified. The organizational structure further enables the education programs to optimize goals and content to meet broader societal demands rather than considerations of a single department. Another gain is that there is a separation of department economy and the economy of education programs, meaning that funds managed by the education program will always be used for purposes benefitting the program.

As described, education funding is funneled to the departments through the buyer-supplier organization based on course delivery. In addition, departments are the administrating unit of governmental research funding provided to the university as well as of external research grants. The proportion of education and research for each faculty member can vary and is decided in agreement with the Head of Department.

The Head of Program is responsible for most aspects of a program, including budget, overall planning and quality management, as well as the study environment, safety and well-being of the students. This gives Heads of Program a strong position at Chalmers, as they have the authority to make both long-term strategic decisions and short-term operational decisions in terms of expected program and course learning outcomes, content, pedagogy, and learning environment. The vision, content and learning outcomes of a program are established through a continuous process lead by the Head of Program in collaboration with students, teachers, and an advisory board with representatives from industry, faculty, and administration. As long as teachers deliver according to the learning outcomes and the agreed assessment methods, they have great freedom to shape and teach the course as they see fit. Heads of Program are in charge of quality assurance, including the program as a whole as well as the individual courses. If a course is commissioned by several programs, one of the Heads of Program is responsible for monitoring and developing its quality with all commissioning programs in mind.

Our general aim with this contribution is to bring forward experiences and examples on how the Chalmers organizational structure has been well suited for carrying out large and continuous development projects, developing and assuring quality, and for allowing our educational philosophy to penetrate through all programs.

EXAMPLES OF EDUCATION DEVELOPMENT AT CHALMERS

Chalmers has a long tradition of developing and implementing educational initiatives and innovations, *e.g.,* the CDIO (Conceive-Design-Implement-Operate) model for engineering education, simulation-based math education, education for sustainable development and entrepreneurial learning in all programs, and more recently “Tracks”, a novel model to ensure flexibility, interdisciplinarity and creativity in engineering education. National and international evaluators have pointed out that Chalmers is outstanding when it comes to continuous implementation of education development among comparable universities in Sweden, and have explained this to be, at least in part, associated with Chalmers organizational model [2]. In particular, the fact that individuals (Heads of Program) belonging to Educational Areas (and, in that role, not to departments) make decisions on program

content and structure has been noted as a success factor, since this enables a unified approach to integrating general skills with progression in multidisciplinary education programs involving several departments. Furthermore, the "buyer-supplier" matrix organization has been noted to shift focus from departmental needs (e.g., to provide education based on existing teacher competences) to prioritizing content and quality of the education based on the needs of students, industry and other stakeholders. The organizational model also has attracted attention, for instance from the Swedish Higher Education Authority, for its ability to create good conditions for systematically leading, planning and developing the education programs and for constantly setting new goals [2, 3]. Furthermore, the model integrates the possibility to drive education quality since different departments may compete to deliver courses, something which has been found to promotes course development. This has led to increased status for teaching among faculty at Chalmers.

Below we present some major education development initiatives introduced at Chalmers in more in detail.

The CDIO Initiative

Chalmers' Mechanical Engineering program teamed up with education programs from The Royal Institute of Technology (KTH), Linköping University (LiU) and Massachusetts Institute of Technology (MIT) to form the Wallenberg CDIO (Conceive-Design-Implement-Operate) project, which later evolved into the CDIO Initiative for engineering education with more than 150 member schools worldwide [4]. The initiative started as a counter-reaction to the recognition that engineering education had become too scientifically oriented with disciplinary barriers between courses and weak links to engineering practice and the professional role [5]. The CDIO initiative aims to form engineers who can develop and operate new products, processes, and systems. CDIO also provides a framework through which general engineering skills such as communication, teamwork, and project management are progressively developed through the integration of these skills into courses and projects. Another part of the CDIO concept is to provide learning environments that support students to work in a practical and collaborative way.

The strategy of CDIO is to develop curricula that integrate disciplinary theory and knowledge, with systems thinking and design methodology, with professional skills such as management ability, ethics, and team-work. Cornerstones in a CDIO program are courses introducing the role of the professional engineer, the integration of general skills into courses with planned progression, and design-build-test projects in which students learn to master the complete design cycle, from the generation of needs and ideas to the implementation and evaluation of a model or prototype. Common models and prototypes produced include services, algorithms, and physical and digital products.

The CDIO model was first adopted by the Mechanical Engineering program at Chalmers, but has since spread, in whole or in applicable parts, to all education programs. When implementing a major curriculum reform such as CDIO, the success often lies in having an organizational structure that allows for change and innovation [2]. Furthermore, strong education program leadership is a key component when designing multidisciplinary curricula with progression of integrated learning and for resolving conflicts between different disciplines [2,6]. These prerequisites have been present at Chalmers during the implementation of CDIO.

The students have been very satisfied with the introduction of CDIO at Chalmers, in particular with the design-build-test modules and the fact that they can make use of their fundamental skills and competences to solve authentic problems. Students helped accelerate the dissemination of CDIO at Chalmers and contributed to the rapid acceptance of the concept among other students, by strongly requesting that a specific CDIO innovation event that they were exposed to in the Mechanical Engineering program should be introduced also in other education programs.

Simulation-based Mathematics Education for Engineering

A professor in computational mathematics approached the Head of Program of the Mechanical Engineering program and argued for a reform in mathematics education by making it more current and based on simulations. Around the same time, the Head of Program received clear feed-back from students pointing out that the connection between math courses and applications were virtually non-existent. Moreover, the concurrent implementation and development of the CDIO model at Chalmers stressed the need for a virtual prototype lab to be able to simulate realistic, computationally complex decision-making situations in design-build-test-projects.

The conditions for a reform of mathematics education were thus good at this point in time and the Head of Program appointed a development team lead by the mathematics professor to develop tailor-made simulation-based mathematics education for Mechanical Engineering. Program level learning outcomes addressing mathematical programming, computations and simulation were outlined by the Head of Program with inputs from the advisory board. Adequate resources were allocated and the focus on the mathematics courses was agreed with the delivering department which designed courses accordingly. Cornerstones in simulations-based mathematics education are [7]:

- full integration of computational aspects (including programming) and symbolic aspects of mathematics,
- computer exercises integrated into applied courses where students solve problems, including visualization, by developing their own code, and
- planned integration of advanced mathematical modelling, programming, and simulations throughout the curriculum.

Since the launch, the reformed mathematics courses have been continuously developed to fill new needs, integrate new pedagogical findings, etc. For example, new development has included a transfer to Python as the general programming environment, tailor-made, electronic textbooks, and digital final exams. The use of simulations has increased motivation among the students to study advanced mathematical concepts and has led to more adequate analyses and simulations in design-build-projects. Employers has given us the feedback that interns, thesis workers and new employees have become significantly better prepared for the managing and solving of open-ended problems, carrying out numerical simulations, and using mathematical software for simulations driven design. It is not surprising that students have become better at programming and using industrial mathematics in the form of advanced software for simulation and design as they have practiced these in both mathematics and applied mechanics courses throughout the education. A positive and perhaps somewhat more surprising result is that the students have become better at dealing with problems with open solution spaces and product development projects. One possible explanation for this is that the simulation-driven mathematics has made it possible for more realistic problems to be analyzed in mechanics applications early in the curriculum. These problems are more open, and the students have been trained to choose mathematical models, formulate the equations and solve them by use of mathematical software and assess reasonableness in the choice of model and the accuracy of the approximate numerical solution instead of practicing solving oversimplified problems with pre-known analytical solutions. Another positive effect is that decision making is trained at a much higher level in the education because authentic systems and structures can be simulated, analyzed and evaluated in the design process and the results can act as basis for decisions and reasoning in a similar fashion as in industry. Thus, the simulation-based mathematics approach prepares the students well for a professional career as a mechanical engineering.

In this change process, it was crucial that the Head of Program had the mandate to supply substantial resources and create space in the curriculum for the implementation of the new courses themselves but also for integrated elements and joint projects. This together with the fact that the Head of Program also has the responsibility for ensuring that content and learning outcomes are regularly evaluated and revised by feedback from industry, students, and faculty, create beneficial conditions for long-term, lasting change.

Development and Implementation of Education for Sustainable Development

In the early 2000s, the interest in sustainability was increasingly expressed by students, industry, and faculty as well as by the leadership of Chalmers. Results from alumni surveys and interviews with stakeholders stressed the need for improved and extended education in sustainable development. Consequently, Chalmers' leadership developed a strategic framework based on the CDIO

methodology that guided the integration of sustainability knowledge and skills in the curricula. The framework identified certain components that should be included in all education programs, but it was also acknowledged that an essential approach was to very closely connect sustainability to the disciplinary domain of the specific education program, *e.g.,* chemistry, computer science, or civil engineering. This approach aimed to ensure the relevance of sustainability education to all domains of engineering and to increase student motivation in acquiring sustainability knowledge and skills, as well as to inspire teachers to include sustainability issues in their teaching. The ultimate guiding principle was that sustainability should be included in all courses where it would be relevant.

This principle requires an integrative approach, *i.e.,* teaching and learning of sustainability takes place within a disciplinary course or a project. To be able to ensure progression and that all required components are covered, a strong program management level is required. Chalmers organizational structure proved to be able to handle this effectively [8]. This philosophy for integration of sustainability was swiftly implemented in all education programs at Chalmers and is used as a model for the present and coming integration of other generic skills in disciplinary courses.

Development and Implementation of Education for Entrepreneurial Learning

In 2016, Chalmers launched a strategic investment in education with the aim to give all students the opportunity to develop an entrepreneurial mindset during their education. The underlying educational philosophy is that all students, regardless of career choice, benefit from gaining experience in entrepreneurship and developing an entrepreneurial mindset. An entrepreneurial approach should therefore permeate all Chalmers education programs by designing learning outcomes, at both program and course level, that promote the creation of good opportunities for students to work entrepreneurially and to develop entrepreneurial skills at both undergraduate and graduate levels. The strategy is to offer entrepreneurial learning at three different levels:

1. **For all:** All students should reach basic competence and skills to apply an entrepreneurial approach. This includes creating value for others by being able to take initiatives, use one's own and others' skills, and deal with uncertainties. To ensure this, there must be compulsory program-specific learning outcomes and teaching activities.
2. **For many:** There should be a wide range of courses with in-depth training of entrepreneurial skills and competences within the elective part of all education programs. Examples of in-depth areas are business development, innovation, social entrepreneurship, and the ability to work interdisciplinary.
3. **For few:** For especially interested and talented students, there must be a range of courses that provide cutting-edge competence in entrepreneurship. These courses include a combination of simulated business scenarios and the development of real R&D-based innovation projects.

The entrepreneurial learning strategy is implemented in the annual agreement process between Heads of Program and departments, starting with the Heads of Program formulating and anchoring relevant program learning outcomes. The program learning outcomes are distributed to adequate courses and are broken down into more detail and specified in the course learning outcomes. If found necessary in the negotiations with the delivering department, the Head of Program offers a development budget.

Although it is too early to draw final conclusions about the impact of entrepreneurial learning in Chalmers' education programs, initial investigation shows promising results. All programs have integrated program learning outcomes relating to expected entrepreneurial skills and there are a wide range of courses with in-depth training of entrepreneurial skills available, as well as a master's program focusing on cutting-edge entrepreneurship competences which is open for all students regardless of background.

Tracks – A Novel Education Model

In 2017, Chalmers' owner foundation decided to invest in three large flagship initiatives to make sure that the university will remain in the forefront of education, research, and utilization in ten years' time. The three initiatives chosen where Learning and Learning Environment (Tracks), Gender Initiative for Excellence (GENIE), and Chalmers AI Research Centre (CHAIR). The education initiative Tracks arose from the conclusion that there is a need for more flexible study paths than presently possible in the program-based education format. The paths needed to allow for students to develop multi- and interdisciplinary competencies and to design more individualized study plans. Another goal was to decrease the lead time for including new technologies and emerging materials in the available education offer. The resulting education initiative, named Tracks, aims to create tracks of courses that lie between existing programs and that belong neither to an Educational Area nor a department but to Tracks itself.

The basic idea of Tracks is to offer project-centered learning supplemented with short courses (modules), on-line learning, self-study, and mentoring, to obtain the necessary knowledge and skills in technologies and science to successfully complete the project [10]. In addition, the courses provide teaching and training in professional skills, covering project management, working in multi- and interdisciplinary teams, ethics, and equality. The courses are organized under a theme, and the themes change regularly to make sure that the content of Tracks is connected to current societal issues and contemporary research [9].

The Tracks initiative was launched in February 2019 with the strategy to develop and implement courses simultaneously. Consequently, the first Tracks course was launched already in May 2019. During the academic year 2019/2020, Chalmers has given 10 Tracks courses involving around

100 students and 25 faculty. The courses have been within three contemporary themes; AI & Automation, Health & Sports Technology, and Sustainable Transportation. This implementation went fairly quick, considering that Tracks does not fit in normal administrative procedures nor in the education program-based structure of the university. Chalmers' well-functioning educational system, with established quality assurance systems and an education management structure suitable for change and development, has facilitated the rapid implementation. *cf.* [11]. Furthermore, since students and faculty are used to taking part in large education development projects there is a readiness and understanding for this kind of initiatives.

DISCUSSION AND CONCLUSIONS

Education development is often a rather slow process as universities traditionally have inherent inertia and resistance to change, with disciplinary department-based hierarchical organizational structures and inflexible career paths that promote disciplinary qualifications. Developing interdisciplinary curricula and cross-university initiatives that involve faculty at several different departments is therefore a delicate task. The Chalmers matrix organization of education based on the buyer-supplier management system has however repeatedly demonstrated that it facilitates development of multidisciplinary, flexible and relevant education by enabling Heads of Program to focus on program design by separating the leadership of education from the leadership of departments. Moreover, the ownership form of the university with an owner that systematically invests the returns on capital to promote Chalmers's position at the forefront of education, research and utilization, has been very advantageous.

An open process for educational development and quality assurance is crucial in order to create trust and transparency between different parts and levels of the matrix organization. Chalmers uses a combined top-down and bottom-up approach to create dialogue arenas to give Heads of Program possibilities to communicate and discuss the program level vision and outcomes with students, teachers, examiners, administrators and Heads of Departments, while at the same time giving these groups ample room for individual involvement and engagement. Arenas for discussing program matters and launching ideas for development include the annual agreement process, program advisory board meetings, program management-teachers' meetings and program management-students' meetings. The annual agreement on course delivery between the schools and the departments is an arena for negotiation and creating a common view on content, pedagogy, and level of the education programs. This has proven to be suitable for change as well as for enhancing quality, and enables a focus on the education program

which in turn lowers the risk of getting programs composed of a set of courses disconnected from each other. From a departmental point of view however, this may cause friction in that department management is not free to plan which education to deliver. Recruitment strategies may be based on other considerations than the need for course engagement, and building teaching experience of young faculty may prove difficult in areas of research expertise where no education is asked for. On the other hand, education needs create incentives for focusing on research with broader societal relevance. One recent example is the wish from education programs to introduce Python as the main programming environment in engineering courses. Initially, the departments could not deliver as asked, but the wish was a driver for skills development and recruitment. There are similar examples where the needs of education programs have been the driver for skills development within departments, e.g., in ethics, group dynamics and sustainability. This has also led to other positive effects such as research opportunities and improved thesis tutoring.

Active student participation is essential for successful educational reform, as students are sources for educational innovations that leadership and faculty might not come up with themselves. Student participation has been shown to promote accelerated implementation and dissemination of educational initiatives to other courses and programs by requiring the same pedagogy and conditions in more courses. The fact that Chalmers' student union has a democratic structure with an elected council and steering committee and that their members are part of Chalmers' management groups and in developmental projects has proven essential, valuable and even crucial for our daily operations as well as long-term strategic development. Organizing the education program management in Educational Areas separated from the departments that employ and manage teacher capacity allows for an agile and responsive education system which promotes rapid course and program development as well as cross-departmental education. However, one necessary condition for this model to work optimally is that programs are cross-disciplinary in nature (or that there is a wish to go in that direction), with courses that are, or could be, delivered by several departments. With such a cross-departmental composition of programs, the buyer-supplier organization truly shines.

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