International Journal of Engineering Education Vol. 29, No. 6, pp. 1312–1321, 2013
Printed in Great Britain
0949-149X/91 $3.00+0.00

University Satellite Project—ITASAT: Creating Technological Capabilities*

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In order to meet the demand for future generations of micro satellites, as well as to build and to accumulate technological capability, the Brazilian Space Agency has established a Government Action which intends to strengthen its space program, mainly through the ITASAT Project (University Satellite). One of the objectives of ITASAT Project, maybe the most relevant one, is to contribute to the human capital improvement by involving university students in the design and development of a small satellite. Thus, this research seeks to understand how capabilities were developed at an individual and a team level, through a process of teaching-learning-teaching, involving a learning-by-doing and learning-by-experiencing support. The methodology used on this research is qualitative, in which the subsystems teams were observed by the researcher during 2010 and 2011. In order to complement and corroborate conclusions based on the observation method, a questionnaire survey was developed, which was applied to a representative sample, aiming to capture students' perceptions regarding learning process and building technological capabilities within the project. Thus, it was observed that students' teams acquired technological knowledge through a teaching-learning method supported by learning-by-doing and learning-by- experiencing processes. The knowledge and skills developed by those teams go beyond the walls of the academy, impacting the Brazilian society and its space industry. Finally, it was concluded that ITASAT Project was a successful learning experience in the field of complex system integration, project management and technical developments accomplished by subsystems teams.

Keywords: technological knowledge; skills; team knowledge

1. Introduction

The use of satellites by the knowledgeable society is of utmost importance, since the domain of their technology and the ability to put them into orbit rank the country among the 40 countries with the capacity to develop, launch and use satellites.

Generally, satellites use sensitive technology and many of them have a high value-added which are not always possible to be acquired without any form of embargo or restriction stipulated by the country that holds technology.

Since an embargo or restriction in obtaining technology, to develop a technological capability enabling create and absorb knowledge and mainly internally develop key technologies, strengthening the technological base and meeting expectations and aspirations of the principal stakeholders [1, 2].

For the development and accumulation of technological capabilities in the space sector, the *Agência Espacial Brasileira*—AEB (Brazilian Space Agency) established the Government Action 4934 to meet the demand for future generations of micro satellites, enabling the design of a university satellite called ITASAT and the development of the Brazilian space industry in this segment [3], thus creating a link among the Brazilian autonomy, the industry and society in the context of the Brazilian Space Policy (Fig. 1).

Generally, the university satellite projects allow students not only to learn and develop satellites using well-known technologies, but also to create innovation. The main focus of learning is the development of technological capabilities of human capital. The development of human capital occurs in each individual and also in the participating teams [4]. In the case of ITASAT Project the teams which deal with the satellite subsystems are formed of students guided by teachers and researchers. This view of subsystems is crucial because a satellite is Complex Products and Systems—CoPS.

The technological capabilities include knowledge, aptitudes and experiences that are incorporated by individuals and teams, enabling generate and manage technological changes [2, 5]. These capabilities are built along the product development process and in the process of integrating the parts into a coherent whole, articulated and aligned with the requirements of the stakeholders [4].

The integration into a systemic whole, which satisfies the functional requirements established, is required in complex systems. For these systems, the technological knowledge of each party alone does not guarantee project success. When dealing with

* Accepted 11 March 2013.

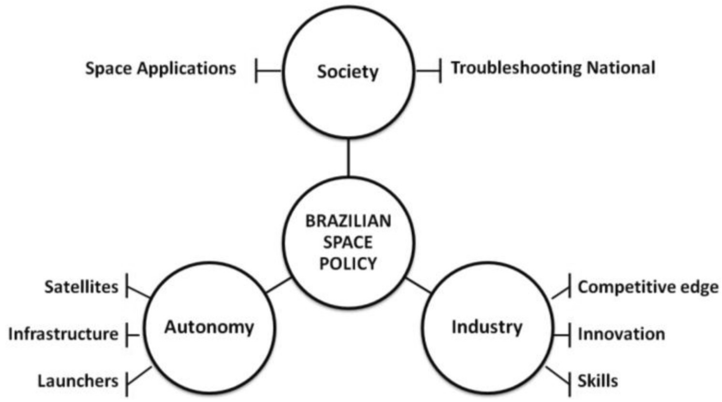

Fig. 1. Triad autonomy, industry and society.

satellite development, the teams are able to integrate various subsystems satisfactorily only after having the domain in the systems integration [6].

In this scenario, only individual knowledge is not enough to guarantee suitable solutions, there is a need for a collaborative environment and teams to enhance the generation and integration of capabilities. The collaborative environment does not happen by chance. In fact, it is promoted mainly by the development of technological capabilities of human capital of managerial nature. The capability of managing collaborative environment is crucial for the engineer's formation.

In addition, in a collaborative environment the teams are involved in a Complex Products and Systems—CoPS. The CoPS can be a group of enterprises, a firm, a production unit or even a project with high cost of production, numerous interactions and intensive engineering [7].

Due to the technological and organizational complexity inherent to CoPS, the development success requires that managers acquire and develop skills in project management and team management network, seeking to align and integrate the efforts used with their strategic goals [7–9].

In general, the learning process, during the project, aims to develop technical and managerial capabilities in students and teams responsible for developing the parts of the system (satellite) and the teachers involved in the project.

The idea is to use methods that develop the ability to conceive, design, carry out and use systems in an approach similar to "CDIO initiative" which aims to restructure education in engineering [10]. In this context, learning methods as "learning-by-doing" and "learning-by- experiencing" are fundamental. The methods are teaching and learning generated from delegated tasks to students. The process seeks to enhance the solution of problems of any complexity within an established strategy [11]. The problems and decision-making should not extrapolate the comfort zone of the students, even though the problems should be complex and challenging according to academic, professional and personal viewpoints. Based on lessons learned, students transfer to one another their knowledge and experiences gained.

In the context described, this paper aims to understand the contribution of ITASAT Project in building and improving the technological capability in human capital dimension in undergraduate and graduate students. Thus, this research seeks to understand how capabilities were developed at a personal level and a team level, through a process of teaching-learning-teaching, supported by "learning-by-doing" and "learning-by experiencing".

The elaboration method of this study was qualitative [12] and it strictly used the observation method [13], in which the researcher participated in the meetings conducted by Teams of Subsystems (TS) as an observer during the years 2010 and 2011, without any direct involvement in the project work. This observation intended to analyze and understand how the process of managing Teams of Subsystems (TS) occurred and evolved, how work was integrated and how these teams reached such technological knowledge.

In order to complement and corroborate conclusions based on the observation method, a survey which was applied to a representative sample was developed, in order to capture students' perceptions about the process of learning and building technological capabilities within the project.

It is noteworthy to emphasize that the ITASAT Project is the first initiative of space management project in *Instituto Tecnológico de Aeronáutica*—ITA (Aeronautical Institute of Technology), where the development of the system is performed by teams, which often have little or no experience in developing and integrating several space subsystems. These teams do not use any specific processes for university satellites, however, they use techniques developed for operational satellites, forcing them to learn by doing, through experimentation and practice, as well as theoretical teaching conducted in classrooms and laboratories, thus gaining technological capability.

2. University satellite project—ITASAT

A satellite university is a functional space platform, as opposed to a conventional orbital platform with its payloads. Usually, the university satellites are placed in orbit as secondary payload (piggyback) of a satellite launch vehicle [14], which is not always known by the team at the beginning of the project. This fact can generate additional complications to the project development, since restrictions may arise from this condition.

Regarding to human capital, Michael Swartwout [15] emphasizes that a satellite university is characterized by being designed and developed by persons in education (students) who perform a significant fraction of the fundamental decisions concerning the design, integration, tests and flight operations. For the author, the formation of human capital is as important as (if not more important than) the "nominal mission" of the satellite itself, i.e. it is the building capacity of the students through the project.

The main feature of the development of a university satellite is not the participation of university but the students' autonomous action during the design, integration, tests and flight operations [15], as an attempt to promote the teaching-learning-teaching supported in "learning by doing" and "learning by experiencing".

With the activities of construction, integration and operation of the satellite, the Project ITASAT aims to educate people in the areas of aerospace engineering and other related areas (electronics, telecommunications, computing, mechanics, materials, thermal, energy generation and distribution, management, operation of satellites among others), creating a benchmark for other initiatives of satellites development in Brazilian universities.

Being ITASAT a technological satellite designed and built by students with the support of their mentors, engineers and researchers, it has prioritized the use of commercial off-the-shelf components with no restrictions for buying and to the market commercial values.

The satellite will go into polar orbit at an altitude of about 600 km (low orbit) [14], with an expected life span of one year. After the end of the "nominal mission", following the code conduct for removing space debris, the satellite will be in the atmosphere, disintegrating in a period of 20 years.

This is an artifact to test concepts, architectures, components and subsystems. Its structure has dimensions of $60 \times 60 \times 52$ cm, with solar panels on its four sides and at its top.

The AEB is responsible for the overall coordination and main sponsorship of the project, while the ITA is responsible for implementing the project and coordinating the participation of other institutions of education and research, while the *Instituto Nacional de Pesquisas Espaciais*—INPE (National Institute for Space Research) is the provider of technical consulting and laboratory infrastructure.

The teachers and students who participate or participated in the project come from various universities and Brazilian teaching institutes, also including the participation of students and teachers of foreign institutions, supported by international cooperation programs, such as the *Technischen Universität Berlin*, TU Berlin.

The project was divided into two phases. The first, from 2003 to 2008, with the aim of studying the feasibility of small satellites configurations and their subsystems, educating human capital, articulating and making a practical collaborative network for the project. The second phase started from 2009, emphasized the implementation of the ITASAT Project.

3. Construction of technological capabilities

The ITASAT is seen as a Complex Product and System—CoPS, where the project execution is dependent on the development and integration of different subsystems. For each subsystem, there is a designated team. The team members are students of ITA, INPE and various educational institutions, principally of the engineering course in different areas of knowledge, guided by teachers or researchers.

The teams are divided into Thermal Control Subsystem, Attitude Control Subsystem, Energy Supply Subsystem, Structure Subsystem, Telemetry and Command Subsystem and Board Subsystem. All supervised and conducted by the Technical Management (TM), consisted of professionals from ITA, INPE and AEB.

The teams work in three environments:

1. Academic: by exchanging information between students and faculty mentors;
2. Innovative: by the guidance of researchers on specific topics and analyzes of revisions made to the subsystems. This environment includes relationships with external technology-based orga-

nizations that develop or use technology. This relationship is designed to ease the adaptation and development of technology to the subsystems needs. Learning occurs through the domain evolution of technological capabilities, and occasionally in the development of innovative engineering solutions, always aiming the construction of complex systems;
3. Productive: by consulting entrepreneurs and technicians responsible for providing equipment and materials to be used in the ITASAT Project.

To integrate activities and establish metrics, Meetings of Integration (MI) among the Teams of Subsystems (TS) are conducted weekly. The meetings have a defined schedule and time controlled. In them, the positions, the proposals and the questions are noted by a reporter.

The reporter elaborates a memory of the issues presented, formalizing them.

Meanwhile, the Technical Management (TM) seeks to adapt the proposals and questions presented to project needs and the capacity of teams to respond to the demand of each stage, keeping the focus on the scope of the project and the expectations of stakeholders. Another important role of the Technical Management (TM) is to promote cooperation, consensus and conflict solution.

Throughout the discussion phase, spontaneous transfer of knowledge is a goal. Commonly, such transfer does not occur in a structured way. During spontaneous meetings people have potential to generate new ideas [16]. At these meetings occur teaching-learning-teaching supported by "learning by experiencing".

In Meeting of Integration (MI), targets are established by the Technical Management (TM), with the consent of Teams of Subsystems (TS). To meet such targets, the teams perform the role of systems engineers, do the role of project architects in their specialties having as premises impacts on project costs, they define the schedule to meet the established targets and the integration among subsystems. In order to undertake the targets, the teams receive the Technical Management (TM) delegates to establish contact with teachers, researchers and market professionals. These contacts seek for getting knowledge for the project development.

These meetings is also a way for the Technical Management (TM) to coordinate the technical discussions and ITASAT development activities while it maintains an integration system which takes into account the strategic goals of the project. The intentional development of capabilities, through strategies and learning plans, was appointed by Peter Senge [16] as an important pillar of the competitive advantage of an organization, in this case, the ITASAT Project.

With the technological capabilities of human capital highlights the inventive collaboration and management teams:

1. Incentive collaboration: the teams develop human capital and earning capacity to keep and transfer knowledge to the various subsystems. The teams learn to use in practice the theories learned in the classroom and bring this knowledge to other subsystems to facilitate the ITASAT integration. The teams considered the goals of the system as a whole, creating conditions for work to occur in a synergistic, integrated and systemic way;
2. Management teams: highlight the strengthening of capabilities in management and coordination of teams and their work, as well as systems integration [6]. The teams learn to decide on alternatives for the adaptation and development of the project, considering the stakeholders' interests.

Three points stand out about team activities. First, the dissemination of knowledge has become a way to insert all the subsystems' network involved. Second, there are cultural barriers to be overcome, since there is competition among different subsystems. Finally, learning occurs in a physical environment, in a virtual environment and mental environment, reflecting the increase in human capital.

At the same time that there is an increase of human capital, it was observed that the teams spread out the knowledge obtained from the academic environment, innovative environment and productive environment. Technological knowledge is not completely shared or transferred. The transfer occurs partly because the absorption capacity of the team is influenced by the knowledge base and the intensity of effort committed [17], and also because the sharing capability is affected by interpersonal characteristics and cultural teams, the context of the project and its motivating factors [18].

In spite of any problem of knowledge stock or knowledge flow, the challenge posed by the project teams to create work together in the research for the new knowledge, in which, one can argue that the teams give a real jump in their learning and in their knowledge stock. The teams are not seen as students to be recognized as teams holding technological knowledge. This recognition occurs to the extent that the teams create, develop and carry out solutions, Many of these solutions are innovative, however, consistent with the requirements of the project.

In the context of ITASAT Project, the relationship model was developed and improved over the time. This is not instantaneous. In fact, the Technical Managers realized the need to coordinate the teams' work providing learning and integration of the work. Therefore, as an indirect result of the project, technological capabilities, organizational and management nature were developed, which promoted learning.

Since the development of capabilities, the information technology is seen as a great ally. The teams seek document management and the document file through the software Tortoise. This software helps in version control of files, allowing the access to team members and other Teams of Subsystems (TS) of updated versions of documents elaborated.

The use of information technology is a tool to support the dissemination of explicit knowledge [19] and memory of knowledge. It boosts the networks that work under decentralized and structured principles. The decentralization happens to the teams and not to the management infrastructure or documentation files.

In addition to the practice of knowledge dissemination, periodic workshops were held, including the participation of researchers from Brazilian universities and other organizations, entrepreneurs and European experts whose purpose is focused on reviewing the activities of the subsystems and presentations, discussions and preparation of Reports of Discrepancies—RID (February 2010: Mission Definition Review—MDR; March 2010: Preliminary Requirements Review—PRR; September 2010: System Requirements Review—SRR, and July 2011: Preliminary Design Review—PDR).

It should be noted that the Meetings of Integration (MI), the periodic workshops and various forms of interactive development in the project creates the "*Ba*", which is a learning space, which can be physical, mental, virtual or a combination of them all, configured to serve as a basis for the creation of individual or collective knowledge, facilitating the creation of knowledge through externalization and combination of knowledge [20], which is internalized and socialized predominantly within the teams [21].

A configuration of structure of teams used in the ITASAT Project is shown in Fig. 2, in general. The figure shows the dimensions to apply the knowledge in the development of subsystems. Most of the applied knowledge is tacit.

The structure model for ITASAT teams seeks to develop subsystems with the ability to absorb and create technological knowledge essential to the project, thus enabling the creation of a base of technological capabilities.

Each subsystem is looking for a technology-based requirement for the development of its activities. Still, this technology base is totally dependent on personal knowledge. This reminds Sanjaya Lall [22] positioning, in which the technological capability is intrinsic and differs from one organization to another, leading to the creation of a technological barrier, since knowledge is not completely shared, transferred or imitated among subsystems.

To overcome this barrier, the Technical Management (TM) acts like a mediator and as integrating element using an interactive and iterative management. A management can accelerate the ripening of technology. This can be supported by the pursuit of technological knowledge from other sources, thereby providing transferring and learning processes, both among systems (projects, research groups or organizations), as within the system itself (Teams of Subsystems—TS). In addition, it is observed that the Technical managers assume the task of proposing harmony and integration of different levels and types of knowledge and technologies that converge to meet system goals and stakeholder needs.

The Technical Management (TM) works with three main challenges for Complex Products and

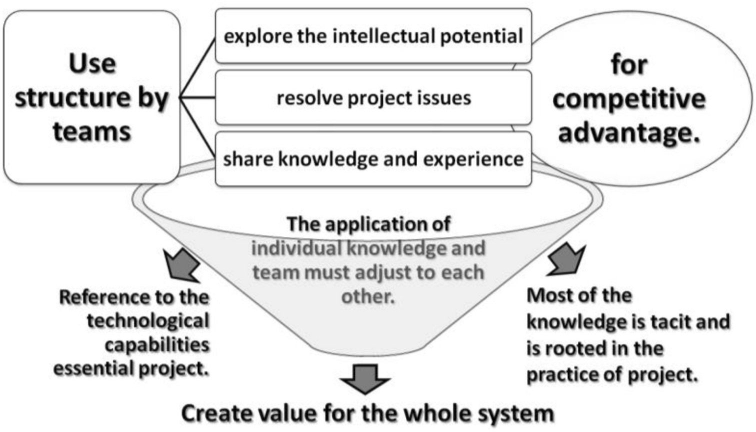

Fig. 2. The Structure model for ITASAT Project teams.

Systems—CoPS. The first is to support constancy in the accumulation of knowledge and capabilities. This includes keeping students in Teams of Subsystems (TS), since them themselves are besieged by enterprises and other projects due to their range of technological knowledge. The second tries to manage conflicts and stimulate productivity of the teams, support teamwork and avoid that individual capacity inhibit the team capabilities. And finally, the third one which aims to prove the integration of satellite subsystems and their coupling in a launch vehicle, even without having the last specifications established.

The development of CoPS is not simple, since they have a large number of custom components and a high level of coverage of their capabilities [7]. Therefore, it is considered that the typical arrangement for building such systems is of interorganizational nature, generally through networks of enterprises or groups that have heterogeneous and highly complementary competencies that when well managed and integrated enable success in producing CoPS. This interdependence has an important role on attenuation of potential rivalries and contributes to the strengthening of learning framework of the network.

A prominent feature that brings complexity to space projects is the need to conduct and manage the integration of the different systems and subsystems that are built by networks of teams which are responsible for the development of the various constituent parts of a product or system. Thus, management, while promoting the coordinated evolution of the project activities, creates conditions so that technological learning occurs in a collaborative covenant, harmonic way providing that individual work is aligned to the teamwork and with the project goals and requirements established by stakeholders.

4. Evaluation of the learning and capability

The observation made by researchers over two years, with no direct involvement in the project is complemented with an assessment that reflects the perceptions of a sample of 22 students about the gain in personal education and technological capabilities, knowledge transfer and impact to the project development, of team learning and the contribution of Meeting of Integration (MI). The size of this sample is representative, in light of the information that in December 2011, seventeen graduate and twenty undergraduate students participated in the project. The evolution of student participation in the project is presented in Fig. 3.

The study sample includes representatives of all subsystems, with the main formation area in sciences. In relation to the its composition, the research was segmented in 45% of graduate and 55% of postgraduate students. Additionally, the researcher noted that 45% of respondents have no more links with the project.

The participation of the respondents in the project is distributed as follows 41% were active on the project for six months, 18% were active on the project between seven months and twelve months, 18% were active on the project between thirteen months and twenty-four months, and 23% were active on the project for more than twenty-four months.

To analyze the contribution of learning processes ''learning by doing'' and ''learning by experiencing'' was compared the gains in capacity stemming from the ITASAT Project with the gains coming from traditional teaching methods in engineering, as can be seen in Fig. 4.

Thus, the contribution of ITASAT was considered by the respondents as relatively better for the development of technical skills in engineering and systems integration. With respect to managerial

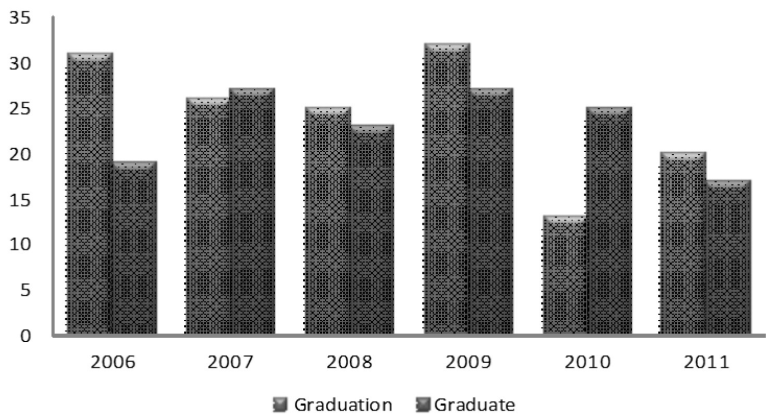

Fig. 3. Annual measurement of students' scholarships in the Project.

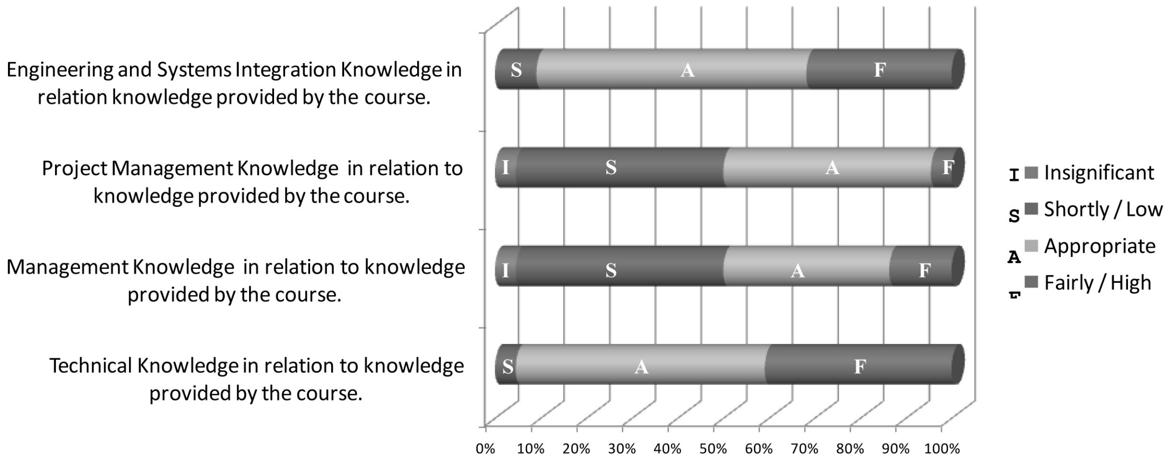

Fig. 4. Gain on personal education and competencies.

capabilities and project management, it was observed that the contribution of ITASAT is not as relevant if compared to the gains provided by the traditional engineering course, but from another viewpoint, one can argue that the project, even if taken as a major goal of the consolidation system ITASAT, allowed the development of knowledge management and project management.

To transfer knowledge, information and experiences to the students, with the goal of developing the Project, it is clear that there is a close monitoring of teachers-mentors and researchers linked to the project. The academic environment and innovative environment exert a strong impact on students' education (Fig. 5). Also, it was observed to be relevant the transfer of knowledge done through relationships with companies that cooperated in the development of subsystems and provided equipment and materials for it.

The knowledge transference from the productive sector to the project participants is still viewed positively, but with some caution. The transfer of knowledge does not occur spontaneously, once the productive sector has the knowledge as economic goods that are shared only when there is some benefit (tangible or intangible) in return. Although technology transference is often confused with knowledge transference within ITASAT, the perception was that relationships with partner companies were responsible for better transmission of information, knowledge and experience of technical nature, or same management as compared with relationships together with the companies who merely offer services or sell products based on a requested demand.

Another important point to be highlighted is the contribution of the team in of the students' managerial and technical learning. The teamwork has contributed to leverage the managerial learning and technical learning in a relevant way (or very important) in the perception of respondents, as can be seen in Fig. 6.

When you have the perception of respondents that management education has occurred in a background, it is acceptable since there was the performance of Technical Management (TM), comprised

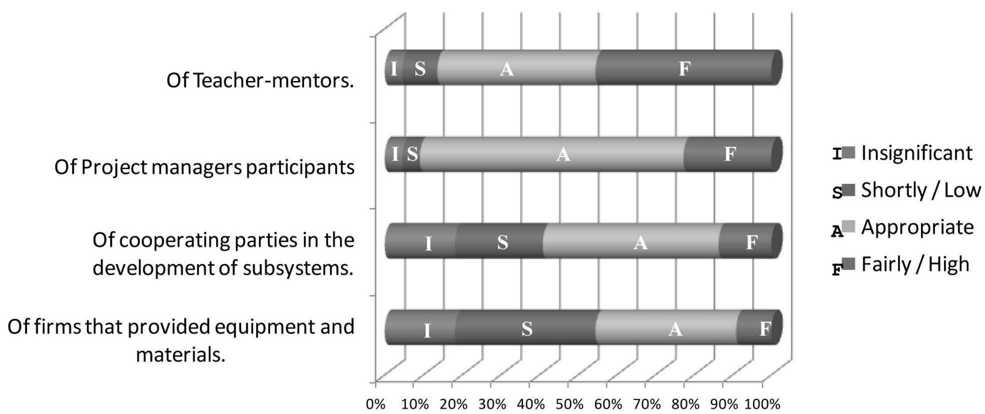

Fig. 5. Knowledge, information and experiences transferred for students to develop the ITASAT Project.

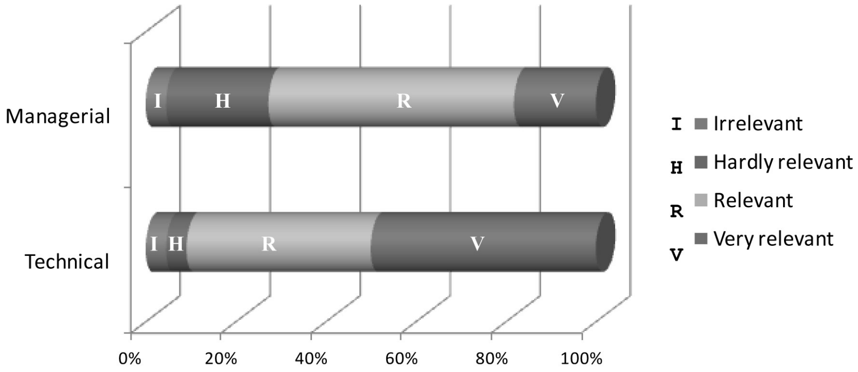

Fig. 6. Contribution of teamwork for learning.

of professionals from ITA, INPE and AEB, which minimizes the conflicts and looks for ways to efficiently manage them, thereby emphasizing the technical learning.

Although the Technical Management (TM) wants the practices of project management to be rooted in Teams of Subsystems (TS) they occur in a timid way, being nucleated in Technical Management (TM). One way to reduce this tendency was to rest in Meetings of Integration (MI) that occurred weekly. For 72% of respondents, the Meetings of Integration (MI) has proved to be adequate, or even primordial, for their technical and managerial education. When dealing with specific education in engineering and systems integration, the perception that contributed adequately or primordial are raised to 77%, but it is reduced to 55% when it comes to education in project management.

Broadly speaking, at the end of the research the researcher sought to verify the perception of respondents as to the field of technical knowledge acquired through ITASAT Project ("learning by doing" and "learning by experiencing") compared to the technical knowledge acquired in courses that use conventional teaching methods (lectures, exercises, laboratories, and others).

The researcher verified that 18% of respondents claim to be far better, 46% better, 27% equivalent and only 9% said that learning by doing and "learning by experiencing" is less effective than those conventional methodologies.

An interesting fact to be mentioned refers to the existence of leaders into subsystems that have become linkages or facilitators between industry and academia, as shows Fig. 7. These relationships can result in a straight professional relationship (or even friendship), which strengthens communication, however, this link can become a form of restricted access to new students in a communication channel already established, become a network of relationships created, restricted to the links already established.

Finally, when trying to understand whether the project has contributed to build confidence in the development of professional activities, 32% of the respondents stated that there was a low contribution and only 23% that contributed to high form. This place is directly related to the interaction of students with the productive sector.

5. Conclusion

In modern societies, knowledge about satellite technology is fundamental, because global communication and information infrastructure depends on a complex web of satellites. Thus, AEB established a Governmental Action, in order to build and to accumulate satellite technological capability, which contemplated the development of a University Satellite Project denominated ITASAT. The mission of the Project is to train and specialize undergraduate and graduate students by building

Fig. 7. Interaction of students with technology-based firms.

technological capabilities, which allow them to develop and to test technological innovations for satellites and payloads; to propose new missions; to develop Brazilian space industry capability; and to enable faster and cheaper access to space. The main partners in this Project are ITA and INPE. Thus, ITASAT Project was designed to contribute for improving human capital, through the involvement of university students, professors, and researchers, in the design and development of a small satellite.

This paper aims to understand the contribution of ITASAT Project in building and improving in the technological capability in human capital dimension in undergraduate and graduate students. Thus, this research tries to understand how capabilities were developed at the individual level and team level, through a process of teaching-learning-teaching, supported by learning by doing and learning by experiencing. The methodology utilized on this research has a qualitative nature, where weekly meetings held by the teams of the subsystems were observed by the researcher during 2010 and 2011, without any direct involvement in the project. In order to complement and corroborate conclusions based on the observation method, a questionnaire was developed, which was applied to a representative sample, aiming to capture students' perceptions regarding the process of learning and building technological capabilities within the project.

Thus, it was observed that students' teams acquired technological knowledge through a process of teaching-learning supported by processes of learning by doing and learning by experiencing.

Such teams, which are capable of providing solutions within the resources, achieved requirements and attributes established, supported by mentor teachers that assisted and guided them through the necessary technological developments. The knowledge and skills developed by those teams go beyond the walls of academia, impacting on the Brazilian society and on its space industry.

Additionally, it was noted the development of management capabilities, which are critical for the success of complex system projects, such as university satellites, because they require the management of several teams responsible for the development of the subsystems, as well as the integration of such subsystems into a whole system, which satisfies all the requirements set by the relevant stakeholders.

The research concluded that ITASAT Project was successful in creating a learning environment, where the human dimension of technological capability was developed.

The teams searched and developed technological knowledge, and they also irradiated the obtained knowledge to their academic and productive environment. It was noted that since technological knowledge is not shared or transferred completely, teams are forced to develop solutions, many of them innovative. Finally, it was concluded that ITASAT Project was a successful learning experience in the field of complex system integration and management of project and technical developments accomplished by subsystem teams.

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