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Developing Research Skills in Undergraduate Students through an Internship Program in Research and Innovation*

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World-class universities have been recognized for their intellectual contributions, among which are the products and outcomes of their research, the impact these products have on the technological and economic development of regions of influence, as well as the education of researchers. Tecnológico de Monterrey is promoting research education among undergraduate students. The Internship in Research and Innovation Program (IRIP) was developed to instill those students with the skills and a motivation to include research and innovation as part of their curriculum. IRIP is a component of the Knowledge-based Development (KBD) model at Tecnológico de Monterrey, one of the central strategies that are consolidating it as a world-class teaching, research and entrepreneurial university. Different outcomes have been achieved since IRIP began, with close relations with the research groups called Research Chairs. The results of the research include international publications, technical developments, innovations and patents, industrial research projects, and an increase in the training of researchers. The purpose of this paper is to present the conceptual and operational model of IRIP as an approach that, using Research-Based Learning (RBL) techniques, facilitates the integration of undergraduate students in research activities. After a summary and comparison of how research activities with undergraduate students are promoted in the top ranked universities, the different approaches (stand-alone, attachment and inserted) that a university can follow for integrating RBL into the undergraduate curriculum are discussed.

Keywords: research at undergraduate level, research-based learning, innovative educational models, Tecnológico de Monterrey

1. Introduction

The need to develop and deploy adequate research and innovation resources as part of any country's economic development and long-term growth is well recognized. To compete globally, countries need a larger number of experienced people to follow a career in research, working on projects that seek the development of technology and innovation in universities and industry. Nevertheless, in the current economic environment, where change and uncertainty are common factors, it is a big challenge to motivate students to go into research and generate innovation.

Research can be motivated in different phases of university studies. Traditionally, research has been a task for graduate students, but now it is also being introduced early in undergraduate programs, as promoted by the results presented in the Boyer Commission Report, Reinventing Undergraduate Education: A Blueprint for America's Research Universities [1]. Different initiatives around the world promote the development of an undergraduate research culture: for example, in the UK at the Reinvention Centre for Undergraduate Research [2, 3]; in the U.S. at the Reinvention Center at Stony Brook [4] the Council on Undergraduate Research [5], and in other projects coordinated by different universities.

In Mexico, Tecnológico de Monterrey has also introduced research activities for undergraduate students. Supported by its mission statement for 2015, different strategies have been developed to prepare qualified professionals, generate scientific, technological and innovative knowledge and support the creation of new knowledge-based companies. In this sense, one of the strategies is to 'foster research at different levels and in post graduate activities'; currently in operation are several institutional programs supporting this strategy, such as the Research Chairs and the Internship in Research and Innovation Program (IRIP, Modalidad de Investigación e Innovación, in Spanish).

The IRIP was developed to motivate those stu-

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dents who have the skills and willingness to engage in research and innovation. The alumni will be able to contribute to the development of a sustainable knowledge-based society, generate practical solutions requiring technological demands, identify the technological state of the art for improving processes and products, deploy new business opportunities, and promote research and innovation methods that can satisfy worldwide needs.

This paper describes this program, its objectives, its structure, and the principal results achieved during its seven years in operation (2004–2011), and the important role that it plays in Tecnológico de Monterrey's Knowledge-based Development model [6]. After a summary and comparison of how research activities with undergraduate students are promoted and coordinated in leading universities around the world, the different approaches a university can follow to integrate research-based learning into the undergraduate curriculum are discussed. This paper is an extended version of [7].

2. Background

2.1 Tecnológico de Monterrey's Knowledge-based Development (KBD) model

Tecnológico de Monterrey is a private university system composed of 33 campuses in various cities across Mexico, as well as a Virtual University system with coverage in Mexico and Latin America, and 12 liaison offices in the United States, Canada, Europe and Asia. With the objective of contributing to the 2015 mission statement and, specifically, one of its strategies, 're-focus research and extension activities', the Tecnológico de Monterrey's KBD model was created. This model consists of six components: (1) an institutional mission statement, which is the central guiding element, (2) social, human and intellectual capital, (3) research products, (4) research funding, (5) entrepreneurial initiatives, and (6) the education model [6].

The KBD model has been deployed and implemented by means of the Research Chair Programs (RCP) since 2003. The RCP was designed to position Tecnológico de Monterrey as a teaching, research and entrepreneurial university to better serve the economic and social needs of Mexico's different regions [8]. The RCP is the trigger force that activates research projects, and coordinates institutional research efforts by integrating senior researchers with undergraduate students. The intention of the RCP was to give continuity to research groups by supporting them with institutional seed funding. A Research Chair is composed of about 20 researchers (3–5 professors, 1 postdoctoral researcher, 2–6 Ph.D. students, 3–4 M.Sc. students and 3–5 undergraduate students) led by a principal investigator specialized in a scientific domain [6]. They are classified in the following knowledge areas: the new economy, resources for development, economic, social and political studies, and business studies.

2.2 Tecnológico de Monterrey's Education Model (MET)

In addition to the KBD model, Tecnológico de Monterrey's Education Model [9] (Modelo Educativo del Tecnológico—MET, in Spanish) has been characterized by the use of information technologies and the systematic incorporation of teaching techniques. MET includes a set of learning components through which Tecnológico de Monterrey fulfills its educational goals. Students assume an active role in the learning process and acquire individual knowledge on the basis of their own experiences and by reflection, under the direction and guidance of their professors. Students acquire relevant, significant knowledge, learn to work collaboratively, improve their learning through continuous feedback from their professors, strengthen their ethical behavior, develop the capacity to conduct research and for self-directed learning, and the ability to stay up-to-date and informed throughout their professional careers.

To achieve these objectives, MET emphasizes collaborative work and uses didactic techniques such as problem-based learning (PBL), project-oriented learning (POL), case-based learning (CBL) and research-based learning (RBL). In this way, knowledge is applied to solving real-life problems, it makes studying meaningful and it becomes the object of critical reflection and social commitment.

2.3 The Internship in Research and Innovation Program (IRIP) and the Research-Based Learning (RBL) Technique

The IRIP started in 2004 as one of four internship programs that Tecnológico de Monterrey offers to all undergraduate students (the other internship programs include: leadership in social development, on-the-job experience, entrepreneurs). Within MET, IRIP is a key teaching–learning process, which uses the RBL technique. RBL is a didactic technique based on the application of learning and teaching strategies aimed at connecting research and teaching by reflecting on and applying the scientific method to problem-solving in the context of a research project. The RBL technique encourages the total or partial integration of the student into a research project that uses scientific methods, under the supervision of a professor. In RBL, 'research is regarded as a theme which underpins teaching at a range of levels; in addition to incorporating research outcomes into curricula, it includes developing student awareness of processes and methods of enquiry, and creating an inclusive culture of research involving staff and students' [10]. The aim of RBL is to get university academics to take positive steps to help students build strong intellectual and practical connections between research frontiers and the students' own learning [10].

In the case of RBL, evaluation may be achieved by assessing results or by assessing the learning process. The main results are a refereed publication (journal article, conference paper, book chapter, etc.), an invention (patent, industrial design, utility model, etc.) or a technical report. For the latter, the phases of the learning process are assessed by following the stages of the scientific method. The main motivation of IRIP is, then, the development of research abilities and skills in undergraduate students through a formal process (learning by doing) that involves training in basic research skills and the opportunity to gain experience through participation in a research project.

2.4 Research methodology of this paper

An action–research methodology was used for designing the IRIP [11]. The main focus of action research is on the capacity of people to analyze and reflect on their own activities. Kemmis and McTaggart [12] suggest that: 'Action Research should have four cyclical phases: Planning—defining the problem and organizing research practices; Acting—implementing plans; Observing—collecting data; and Reflecting—revising actions and outcomes, and planning new actions derived from what has been learned.' The authors of this paper were responsible for a second cycle in the action research methodology, starting in 2008, planning, designing and deploying new strategies and a new academic program structure for the IRIP.

3. Internship in Research and Innovation Program (IRIP)

3.1 Objectives and benefits

The IRIP's aim is to have students develop research and innovation skills through the practical experience of working in research teams. Upon completion of the internship the student will be able: (1) to apply the scientific method to the solution of research problems, (2) to write scientific documents, such as technical reports and papers, (3) to apply the method of invention and development of patents, and (4) to participate as co-inventor of patent and other intellectual property products.

Through participation in IRIP, students will obtain different benefits, such as: (1) participation in applied research and/or technology development projects that aim to create and apply new knowledge; (2) acquisition of significant knowledge during the development of research projects using leading technologies; (3) connection with scientists in national and international institutions; (4) a competitive advantage in their professional education and life plan; (5) improvement and development of several skills, such as, teamwork, oral and written communication, time management, critical thinking, problem-solving, specialized training and leadership

3.2 Academic program structure

The IRIP's academic program structure consists of four courses outside the curriculum and four internships (Fig. 1). Courses outside the curriculum are designed to develop basic research and innovation skills and the main topics of these courses are: (1) Methodology for Research and Innovation (MRI), (2) Comprehending, Evaluating and Structuring scientific and technical documents (CES), (3) Intellectual Property (IP), (4) Development of Technological Entrepreneurial skills (DTE) and (5) Qualitative Research Methods (QRM). During the Research Internships (RI), students develop a research project monitored by a senior researcher within a Research Chair. Courses outside the curriculum are equivalent to a four-hour a week class (1.5 credits), while research internships are equivalent to an eight-hour a week project (3 credits) during one term (16 weeks).

There are two mandatory courses: MRI and IP. After completing these courses, the student has some options: (a) Select two courses of 1.5 credits each: CES and DTE; (b) Select one 3-credit course: QRM; or (c) Expand the scope of the research through a fifth research internship. The decision about how to structure the IRIP depends on the scope of the research project and student interest; the IRIP can be tailored to each student.

Besides the experience gained when participating in research projects, students are expected to have participated in writing technical and scientific papers, drafting a patent, and presenting their

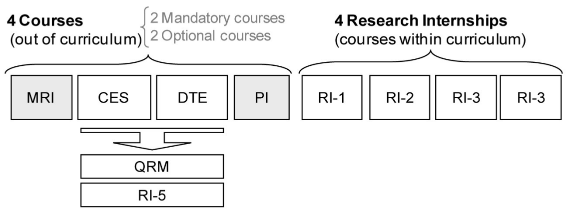

Fig. 1. IRIP program structure

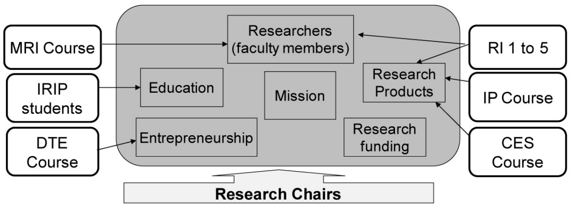

Fig. 2. IRIP elements supporting Tecnológico de Monterrey's KBD model.

research results in national or international events. Many students also take the opportunity to participate in research groups abroad, acquiring international research experience and creating technology-based spin-off companies.

3.3 The IRIP Supporting the Knowledge-based Development (KBD) model

The KBD model has guided the transformation of the Tecnológico de Monterrey from a teaching university into a teaching, research and entrepreneurial university [13]. Figure 2 shows the main components of the KBD model (shaded boxes) and how the IRIP courses and outcomes support each model element (white boxes).

The mission of the KBD model is to carry out research and graduate education in the areas relevant to Mexico's development. The IRIP structure supports the KBD model in the following ways.

- Courses prepare students in basic research skills, supporting the development of researchers.
- The creation of research products (technology developments, inventions and publications) is fostered by preparing the students in two courses: CES and IP. Research products are the outcomes of the projects carried out during the research internships under the guidance of different professors.
- Entrepreneurship is promoted in the DTE course, in which students initiate spin-off of technology-based enterprises.
- Undergraduate education is enhanced by student acquisition of research skills and experience. IRIP alumni usually pursue graduate studies.

After seven years in operation, the IRIP has grown and incorporated students from several disciplines. Figure 3 shows the increase of the following numbers per term: new students registered in the program, enrolled students (students taking courses in each semester), and total IRIP students (total number of students registered in the IRIP, who may or may not be taking courses during the term). Four students starting the program in January 2004, and from there the number rose to 220 students registered in the program in May 2011.

Table 1 shows the number of new students distributed in the four different schools. From 16 students who started in 2004, 80 students joined in 2011. Of the new students for 2011, 35% were from

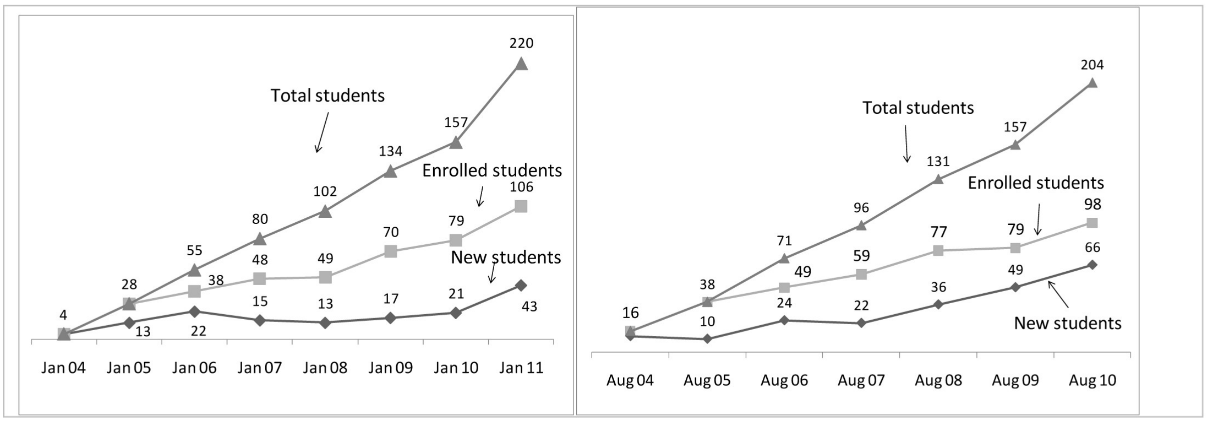

Fig. 3. Number of IRIP students per term.

Table 1. Number of new IRIP students per year and school

School	2004	2005	2006	2007	2008	2009	2010	2011	Total
Eng. and Information Technology	8	11	19	20	26	26	32	29	171
Biotechnology and Food	1		17	12	17	25	28	22	122
Medicine and health sciences	5	9	10	4	4	13	22	27	94
Business, Social Science and Humanities	2	2	0	1	2	1	1	5	14
Architecture and Design	0	1	0	0	0	1	4	1	7
Total	16	23	46	37	49	66	87	84	408

the Engineering and Information Technology School, 32% were from the Medicine and Health Sciences School, and 26% were from the Biotechnology and Food School.

4. Main results and performance indicators

Research products and the preparation of researchers are two of the KBD model elements that motivate the IRIP program. In terms of preparation of researchers, the number of students who have graduated who have been in the IRIP is one performance indicator. Figure 4 shows how the number of graduated students has begun to grow, especially over the last year. The total number of students who have graduated since 2004 is 100 (see Fig. 4). The following majors are the most popular among graduated IRIP students: biotechnology engineering (28 students) and mechatronic engineering (14 students).

It is important to mention that there is a delay in the achievement of results in this kind of program. Most of the students who enter the IRIP are in the initial years of their bachelor degree program and their insertion in research projects is gradual, so the results they achieve will be during their senior year. From May 2008 to May 2011 graduated IRIP students generated more than 115 scientific research products. These research products are distributed mainly as participation in: patents and inventions, national research awards, international research competitions, refereed indexed journals, papers and posters in international and national conferences, white papers published on internet sites, technical reports presented in international internships, and master theses developed during undergraduate studies.

5. Discussion

Universities pursue different strategies to successfully link teaching and research, and implement RBL techniques for undergraduate students. Griffith [14] summarizes these strategies as follows: draw on personal research in designing and teaching courses; place the latest research in the field within its historical context in classroom teaching, design learning activities around contemporary research issues; teach research methods, techniques and skills explicitly within programs; build small-scale research activities into undergraduate assignments; involve students in departmental research projects; encourage students to feel part of the research culture of departments; infuse teaching with the values of researchers.

Several strategies can be combined in different ways, with special attention given to the integration of students into departmental research projects, and to the teaching of research methods, techniques and skills explicitly within programs. Some of the focused programs that top ranked universities have implemented to introduce research activities to undergraduate students are described below. After a comparison between these efforts and the one developed at Tecnológico de Monterrey, an abstraction of different approaches that universities could follow to introduce research activities to undergraduate students is discussed.

5.1 Related programs

The top eight universities around the world were analyzed to identify the main programs introducing research activities to undergraduate students, and the different approaches these universities use for promoting and displaying the information related to undergraduate student research activities. Universities were selected using the THE–QS (Times Higher Education–Quacquarelli Symonds) World University Rankings [15] and the Academic Ranking of World Universities (ARWU) [16]. The universities selected are those included in one of the following: the top five of the THE–QS general rank in 2009; the top five of the THE–QS citations per faculty rank in 2009 and the top five of the ARWU world rank in 2009. There were eight universities that appeared in the top five in any of those rankings in 2009: Harvard University, Stanford University, the University of California, Berkeley, the University of Cambridge, Massachusetts Institute of Technology (MIT), California Institute of Technology, the University of Oxford, and Yale University

These top universities offer their undergraduate students different opportunities for doing research in different formats. Some programs offer academic credits, scholarships or student wages for participation in research projects during an academic year or summer period; others have available funding mechanisms that may be requested either for the student or for the tutors. Several programs are managed by the Undergraduate Advising Office, others by the student employment office, and still others independently by each department in the

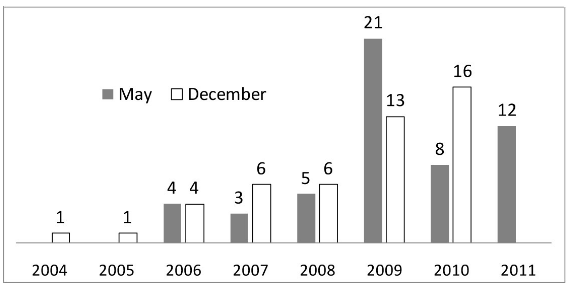

Fig. 4. Number of IRIP students who have graduated.

Table 2. Undergraduate research programs at top universities according to ARWU and QS world rankings

University	Program	Aim / Scope	Funding
Harvard University [17-21]	Faculty Aide Program	IT encourages professors to hire undergraduate research assistants and provides a platform to advertise the position.	Yes
	Harvard College Research Program	Supports student-initiated scholarly research and creative endeavors undertaken with faculty guidance.	Yes
	Mellon Mays Undergraduate Fellowship Program	Minority students and others with a commitment to racial diversity. The program is focused on art and science areas.	Yes
	Dean's Summer Research Awards	Rising seniors who receive financial aid have the opportunity to devote the summer to thesis research.	Yes
Stanford University [22]	Grants for students	Small Grants, Angel Grants, Major Grants, Chappell Lougee Scholarships, and Conference Grants.	Yes
	Summer Research College	Academic workshops and events for students	Yes
	Honors	Senior students who will do in-depth research.	Yes
	Honors Writing Program	It offers support and advanced classes for writing a thesis.	No
	Faculty Grants for Undergraduate Research	Individual faculty members may receive funds to involve undergraduates in their research.	Yes
University of California, Berkeley [23-25]	Undergraduate Research Apprentice Program	Students with mentoring (without payment), earning 1 unit of academic credit for each 3 hours of research work.	Yes
	Haas Scholars Program	Opportunities for academically talented, financial-aid-eligible in all mayors to engage in a sustained research, field-study or creative project, often their senior honors thesis/project.	Yes
University of Cambridge [26]	Undergraduate Research Opportunities Program	It allows any undergraduate not in the final year of study to gain an insight into the research being undertaken by the world-class academics that teach at the university.	NA
Massachusetts Institute of Technology [27]	Undergraduate Research Opportunities Program (UROP)	Students can work on cutting edge research. UROP supports research partnerships between MIT undergraduates and faculty. Students can receive academic credit, payment or work on a voluntary basis.	Yes
	The IAP Research Mentor Program	Links undergraduates who have never done a UROP with upper-class students who have at least one year of UROP experience and/or MIT faculty.	No
California Institute of Technology [28]	Summer Undergraduate Research Fellowships	It introduces students to research under the guidance of research mentors. Students experience a creative intellectual activity.	Yes
	MURF Undergraduate Research Fellowships	Provides support to spend a summer in a research laboratory. MURF supports Caltech's commitment to training a diverse set of science, technology, engineering, and math leaders.	Yes
	NASA Undergraduate Student Research Program	It consists of a 10 week research experience at a participating NASA Center under the supervision of a technical mentor.	Yes
Yale University [29]	Yale Science and Engineering Research for Undergraduate: Perspectives on Science & Engineering	A year-long course and summer program providing students with an introduction to scientific research and research opportunities.	Yes
	Yale Science and Engineering Research for Undergraduate: Science, Technology & Research Scholar	Provides first year students through seniors with an integrated experience in research, course-based study and development of mentorship skills.	
	Yale Science and Engineering Research for Undergraduate: Faculty and Departmental Research Programs	Provides a wide variety of research opportunities to students. Undergraduates enjoy access to the research laboratories and professional degree-granting programs.	
University of Oxford [30]	SURE Summer Research Program	Students work for 10 weeks in the summer with faculty. The SURE-Oxford students also participate in the larger SURE program by attending weekly career mentoring and ethics sessions, and competing in the final poster competition.	NA

university. Table 2 presents a list of these programs, with a brief description, and identifies which programs have opportunities for students to obtain funds.

Different strategies are also deployed by these universities to promote and display the information related to undergraduate students, Table 3. The first section presents useful information for students that is available on the internet. The second section shows the principal means for promoting undergraduate research results. As shown in Table 3, at Tecnológico de Monterrey there is an office responsible for promoting the IRIP program in the student body (18 000). The primary approach is to promote the integration of undergraduate students in Research Chairs through diverse mechanisms. A student, after taking the IRIP courses and according to his/her research interest, has the opportunity to participate in research projects, guided by a senior researcher, and learn from the experience of being involved in a research group. This is one of the main differences noted in the approach followed by other universities; the RCP is the platform for doing research at the undergraduate level: in this program funding mechanisms, research projects, researchers, and research results are all integrated.

To publish results achieved by undergraduate students there are diverse mechanisms:

- The campus newspaper (*Panorama*) publishes research news of special note.
- In the university's annual Research and Technology Development Conference (in Spanish, Congreso de Investigación y Desarrollo Tecnológico), there is a special track for undergraduate research projects.
- The research magazine *Transferencia* publishes research results and graduate information.

Table 3. Main characteristics and information on Web sites about undergraduate research programs

		Universities								
		Harvard	Stanford	California, Berkeley	Cambridge	MIT	California Institute of Technology	Yale	Oxford	*Tecnológico de Monterrey*
Information for students	Introductory Seminars		X	X			X	X	X	X
	Office of Undergraduate Advising and Research		X	X		X	X			X
	Research Services Division Office				X		X			
	Web page with information for doing research at the university	X	X	X	X		X	X		X
	List of academic departments	X	X	X	X	X	X	X	X	X
	List of mentors by department	X				X				
	Database for research opportunities	X	X	X	X	X				X
	Link to libraries	X	X	X		X	X	X	X	X
	International research experience database	X	X	X		X	X			
	List of funding opportunities / offices	X	X	X		X		X		
	Funding Sources for International Experience database	X				X				
	List of prizes for undergraduate research		X							
	List of journals for publishing research arts.		X							
	Research standards, policies & IPR				X	X	X		X	X
	Support for commercializing research products/services				X		X		X	X
Promotion of research results	Research Program Newsletter	X			X	X				X
	Undergraduate Research Journal(s)	X	X	X			X	X		
	Symposium / Conference / Workshops for Undergraduate Research	X	X	X			X	X		X
	Undergraduate Research Association	X								
	Other student groups	X								

5.2 Three different approaches to introducing research activities to undergraduate students

From the previous review, three approaches are identified that can be used in a university for introducing research activities to undergraduate students. These proposed approaches that use Research-based Learning techniques (RBL) are shown in Fig. 5.

5.2.1 Stand alone approach

The research task is introduced in the classroom and promoted by the researcher. A research project is assigned to several students as part of the work to be developed in a specific course. The professor responsible for the course is the advisor, and the students develop the research. A research report is generated for presentation in the course and, in some cases, this report can be formatted into a research paper and evaluated for publication in a formal research environment (usually a conference). The main advantage of this approach is student integration into research activities, using a formal learning technique, but limited to the restrictions of an academic course in terms of time and resources. Research results may vary depending on the abilities of a single student for doing research by himself / herself. The stand alone approach is commonly used in summer research programs coordinated by other universities.

5.2.2 Attachment approach

The student has to perform a research task as a requisite for graduation and the task is usually based on a research profile defined for the bachelor degree. The student is 'attached' to a professor and develops a complete research project in a specific

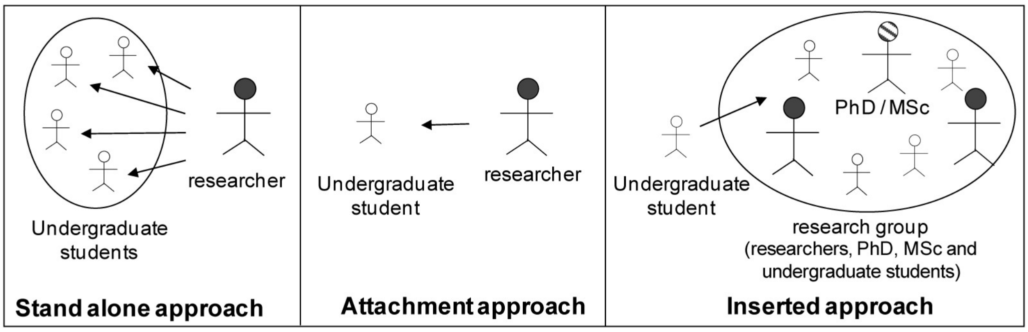

Fig. 5. Three approaches for introducing research activities to undergraduate students

topic (usually within the professor's main research interest). A technical research report is generated by the student, and in some cases a kind of thesis is the final research product. This report can generate a publishable work in the format of a poster or an article in a conference. The attachment approach can work in large research projects coordinated by experienced, recognized researchers, but for students who are starting their research career, the integration process may be difficult, which may cause the student to leave the research or end it with very limited results.

At Tecnólogico de Monterrey, the attachment approach is used in some bachelor degrees, such as the Bachelor of Science in Chemistry, where one requirement for graduation is to develop a research project and turn in a formal research product or report. Research results under this approach may have a larger scope, but the approach has limitations in terms of time, and resources may be low, since the main objective is to deliver a formal research report, usually in the form of a thesis. Another example corresponds to the Bachelor of Science in Industrial Physics, given the research profile this academic program develops.

5.2.3 Inserted approach

A student is interested in doing research out of her/his personal interest and the university supports these students by integrating them into research groups. Undergraduate students participate in the Research Chairs. The students gain the experience of working in collaborative research environments, in addition to developing different research skills. A special certificate is given to students who complete the research courses and work. Research results are intrinsically generated, since these are the logical outputs of research projects. The main advantage of this approach is the experience that undergraduate students have when working in a collaborative research environment, where senior researchers, Ph.D. students, and M.Sc. students are involved. This approach also accelerates the integration of undergraduate students into research activities as a result of the collaborative environment supporting them while they are carrying out research.

In the inserted approach researchers and students can get results more rapidly, as they are participating in well-established, long-term research projects that usually can get financial support. Most of the students who work under this scheme go on to complete a graduate degree. The sum of the research groups' efforts in the inserted approach means rapid project results in the short term because specific research areas are consolidated. This contrasts with the 'stand alone' approach in which the results are diluted and are usually within a narrow scope.

6. Conclusions

After eight years of operation the IRIP program, in addition to keeping growing, has achieved several successful results. The IRIP implementation and its integration into the Research Chairs Program has supported the deployment of the Tecnológico de Monterrey's KBD model, as part of one of the key strategies to consolidate the institution as a world-class teaching, research and entrepreneurship university. The development of intellectual capital, the creation of research products (technology developments, inventions and publications), the promotion of entrepreneurship, and the education of undergraduate students has been enhanced by the different IRIP strategies deployed together with the efforts of the Research Chairs.

These successful results can be measured by different indicators, such as the number of indexed journal articles, conference papers, and technical reports generated by undergraduate students. Motivating indicators that have shown the fruitful results include the increased number of undergraduate students participating in research projects, the successful experiences and the graded recommendations of IRIP students by senior researchers.

Tecnológico de Monterrey uses the inserted approach, showing a different way of incorporating research into undergraduate student curricula. This approach, implemented through the Research Chair Program, has demonstrated successful results.

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