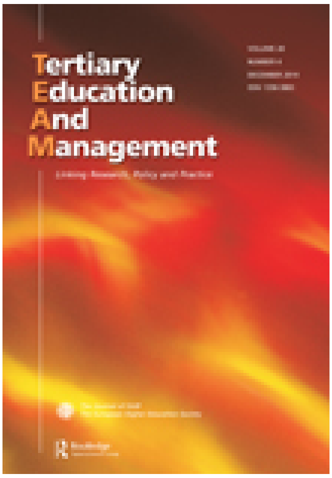

Tertiary Education and Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rtem20

The start-up, evolution and impact of a research group in a university developing its knowledge base

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Published online: 15 Sep 2014.

To cite this article: Hugo Horta & Rui Martins (2014) The start-up, evolution and impact of a research group in a university developing its knowledge base, Tertiary Education and Management, 20:4, 280-293, DOI: 10.1080/13583883.2014.948907

To link to this article: http://dx.doi.org/10.1080/13583883.2014.948907

Tertiary Education and Management, 2014
Vol. 20, No. 4, 280–293, http://dx.doi.org/10.1080/13583883.2014.948907

The start-up, evolution and impact of a research group in a university developing its knowledge base

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(*Received 23 June 2014; accepted 21 July 2014*)

This article focuses on the understudied role of research groups contributing to develop the knowledge base of developing universities in regions lagging behind in human, financial and scientific resources. We analyse the evolution of a research group that, in less than 10 years, achieved worldwide recognition in the field of microelectronics, with an impact on both engineering research and teaching activities at the University of Macau. Our analysis concludes that voluntarism and loose organizational structures from the start stimulate the development of solid scientific agendas and institutional identity, and that counter-intuitive policies, including academic inbreeding, may also be needed and unavoidable in this effort. The use of these counter-intuitive policies and their effects, however, can be mitigated by transforming education to highlight high levels of internationalization and quality standards with measurable outcomes. This requires the committed involvement of research group leaders in both research and education. Lastly, another key component of university development may lie in hiring and giving freedom to young promising scholars with the will and drive to lead and act.

Keywords: research groups; institutional change; leadership; engineering and technology; inbreeding

Introduction

The role of universities in creating and diffusing knowledge is indisputable in today's knowledge societies (Simha, 2005). Academic research, in particular, is increasingly becoming more funded, structured, collective and dependent on a mix of collaborative and competitive dynamics and incentives (Billot, 2010). Multiple national and global pressures driven by new public management, global academic competitiveness and rankings further add to fostering change (Tie, 2012). In this framework, the need to better understand academic research and its mechanisms becomes more intense, as policy-makers, managers and academics seek out greater research performance and quality (Rey-Rocha, Garzón-García, & Martín-Sempere, 2006). Since the seminal works of Hagstrom (1965), Latour and Woolgar (1986) and Ziman (1983), the study of the organization, management and collectivization of research practices and the outputs of research groups, teams and laboratories has developed immensely. Recent studies have

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focused on research management (Mintrom, 2008), creative environments (Hemlin, 2006), interdisciplinary teams (Sá, 2008), team collaboration (Adams, Black, Clemmons, & Stephan, 2005), knowledge transfer (Pfotenhauer, Jacobs, Pertuze, Newman, & Roos, 2013), research leadership (Hansson & Mønsted, 2008), organizational size (Kenna & Berche, 2012) and well-being at work (Torrisi, 2013; see also Jung, 2014).

However, while certain issues related to academic research and its mechanisms have been studied extensively, others have received less attention. Even though the (in)compatibilities of the teaching–research nexus are heatedly debated as pertinent to both the research and teaching missions of universities (Shin, 2011), few studies have explored the influence of university research groups on postgraduate teaching (e.g. Grevholm, Persson, & Wall, 2005). Furthermore, to the best of our knowledge, there is a current lack of studies that focus on how research groups can foster research capacity building in higher education systems with limited knowledge base and investments. These two issues are of critical importance for universities that strive to improve their research activities and impact, especially for those in emerging regions throughout the world (Nour, 2011).

This study contributes to knowledge on research groups and their ability to foster research capacity building and postgraduate development at universities as they evolve. It involves a case study analysis of the State Key Laboratory (SKL) of Analog and Mixed-Signal Very Large Scale Integration (AMS-VLSI), a research group based at the University of Macau. Based at a teaching-oriented university without a research tradition, the creation and development of this research group strengthened the university's knowledge base, achieving worldwide recognition for quality within a relatively short time span. As it developed, the group contributed to transforming postgraduate education in the field of electronic engineering at the university, as well as reversing declining enrolment numbers within the Faculty of Science and Technology (FST). Due to a purposeful leadership, coupled with institutional freedom to act, this research group was able to thrive in a context of scarce human and financial resources for research. Its development highlights important policy and managerial implications for universities from emerging regions that are currently striving to build up their knowledge base in terms of research and postgraduate capacity. The following case study analysis draws from narrative interviews performed with the founders and research line directors of AMS-VLSI, as well as documental and quantitative data (following similar approaches in the literature; see Sinisalo & Komulainen, 2008). The secondary source of data of this study is from the University of Macau and Macao's Special Administrative Region of China (SAR) governmental entities.

The context: the Macao higher education system and the University of Macau

Macao is a SAR of China that has operated on the 'one country, two systems' principle since its transition from Portugal to China in 1999. A lack of natural resources forces Macao's economy to rely on human capital in a service industry dedicated to gambling, tourism and hospitality (Tang, 2014). Usually referred to as the Las Vegas of the East, Macao has been developing in the shadow of Hong Kong, which possesses a larger economy, population, a more qualified labour force and prestigious universities. According to World Bank data, the gross expenditure in research and development (R&D) as a percentage of the GDP in Macao is negligible, having remained unchanged at 0.1% since 2001. Even though the number of researchers per million inhabitants in the region has almost tripled over the last decade, it is rising from very low figures (from 260 in

2001 to 734 in 2010) and continues to lag behind when compared internationally. These figures suggest a long-neglected investment in science and marginal R&D activity (Li & Bray, 2007).

Macao's higher education system evolved at a faster rate than the research system. The creation of the University of East Asia in 1981, purchased in 1988 by the Macao Foundation with public funding and renamed the University of Macau in 1991, represented the establishment of the first modern university in the territory. In the early 1990s, the higher education system comprised the University of Macau and two other universities, all of them offering employment-oriented courses (William, 2005). These universities were teaching oriented, with barely existing graduate education and insignificant research activities. In 1992, the total number of international publications of the University of Macau was three. However, as Figure 1 shows, the University of Macau has been and continues to be the research flagship of the territory in terms of knowledge production. The University of Macau was solely responsible for the territory's international publications, even though its volume of publications was very low when compared to other small territories. In 2012, Macao had 714 international publications, compared to 16,012 for Hong Kong and 15,272 for Singapore.

Today, the number of universities in the territory has grown to 10, and the gross enrolment ratio in tertiary education from 27% in 1999 to 68% in 2011. In 2011/2012, out of the 26,217 students enrolled in the universities, 13% are in master's courses and 2% doctoral courses. However, due to the economic activity of the Macao SAR, the difficulty of attracting students to study in the Science and Engineering fields persists. According to UNESCO data, in 2001, only 3% of tertiary students graduated in the science and engineering fields. This figure rose to 7% in 2011, meaning that the need to contribute to qualify the labour force and increase technical qualifications remains a challenge for the Macao SAR government and Macao's universities (Tang, 2014).

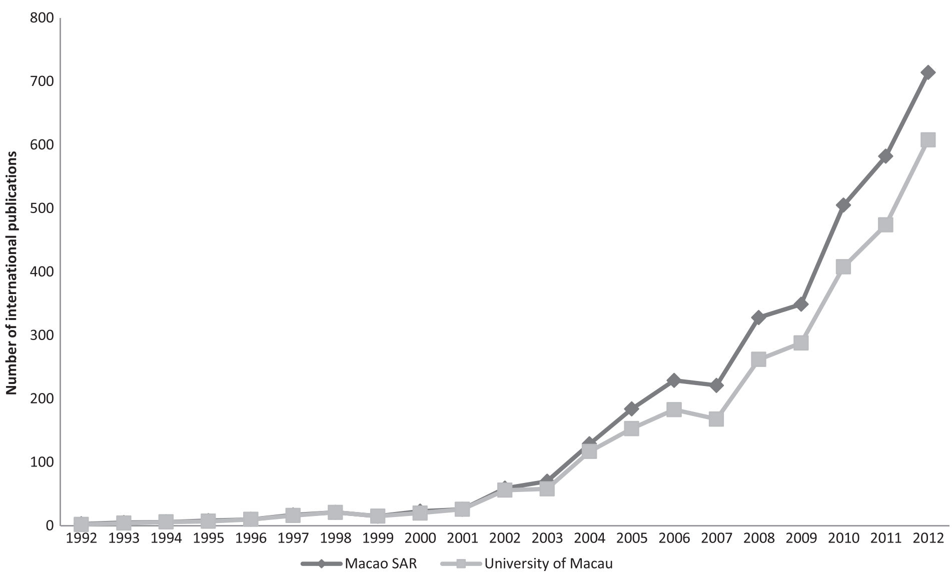


Figure 1. Total number of international publications, Macao SAR and University of Macau, 1992–2012.
Note: Data obtained with the command 'Affil( )'. Source: Scopus.

The first years: the vision to foster research and engineering education at the University of Macau, and the creation of the AMS-VLSI

In 1992, the founder of the AMS-VLSI research institute arrived at the University of Macau as a visiting associate professor. This was six months after completing his PhD and following several years of experience as a member of the academic staff at the Engineering School of the Technical University of Lisbon, where he was a co-founder of a microelectronics research group. The change from one location to the other was mainly driven by an invitation from Macao's higher education authorities. Two months after his arrival, he prepared a report that gathered his first thoughts and proposals to enhance the research and teaching potential of the University of Macau (Martins, 1992). This (non-commissioned) report contained proposals for changing the curricula of electronic engineering, setting research-focused master's programmes and establishing the basis for the launch of doctoral programmes. This report was offered to and accepted by the management of the university as a guiding document to define the University of Macau's research and teaching strategy for the coming decades.

The report considered the University of Macau to have a good administrative organization, ICT support structure, conditions for teaching, general library and, most importantly, a core of interested and determined bachelor students eager to learn. The same report considered the University of Macau to be mostly a teaching university with ossified curricular structures, where learning was focused on general and obsolete knowledge associated with teaching not being supported by research. Regarding engineering courses, the report considered them insufficient to prepare students for the job market: 'they [the students] only receive formation at a very elementary level … I can say that a significant number of experiences that I have seen here in the electronic engineering laboratories are made at the high school level in Europe' (Martins, 1992, p. 3). The report further highlighted the use of old technologies in learning, lack of real experience in fieldwork projects, overload of classes for the students, assignments and final examinations that curtailed any possibility of integration in research activities, and the non-existence of specializations in engineering majors. In this context, the number of enrolments in the FST was decreasing, and academic staff members were under threat of having no students to teach soon (Martins, 1992). The report hinted at the cause of this: 'If the electronic engineering program is now behind 10 or 15 years, in 5 years' time it will be 20 or 25 years behind the rest of the world and nobody will come here to study' (Martins, 1992, pp. 11–12).

Based on this assessment, several measures took place with the support of the University of Macau management and the FST, where, after a few years, the founder of AMS-VLSI would become dean and vice-rector. That the university management used the report of a recently arrived young academic in the 1992–1993 school year to dramatically improve teaching and research suggests that there was a perceived need for change at the university (see By, 2005). Aside from this, and most importantly, the situation was somewhat of a crisis in the engineering programmes, as student numbers had been declining for a few years in a row. Due to the report, the engineering bachelor curriculum was transformed to include specializations, project disciplines and the social sciences and humanities disciplines (see Portaria 229/93/M, 1993). All of this was complemented by campaigns in high schools to attract more students to engineering and technology. Over the following years, these campaigns led to the gradual increase in enrolments, thus permitting the university to establish consolidated bases for the launch of graduate education and research activities. Such outreach campaigns in high schools are understood today as critical to attract children to the fields of science and technology, both of which have suffered from declining youth interests (Davis, Yeary, & Sluss, 2012).

In 1993, the course 'introduction to research' became mandatory for master's programmes (see Portaria 179/93/M, 1993) as a lever to promote research activities. It was with master's students that research on microelectronics emerged at the University of Macau, with a project titled UMCHIP, which was submitted to the University of Macau Research Committee for the design of an integrated circuit in collaboration with the Technical University of Lisbon. The UMCHIP project marked a turning point for the University of Macau in terms of graduate education and research. It led to the first integrated circuit designed in Macao. This circuit performed with software donated by the Technical University of Lisbon and was created without laboratory or testing equipment on a budget of just €4000. It also received one of the first research grants given by the University of Macau Research Committee, which had only funded participants to attend conferences at a time when the entire university published three papers in one year. The university's participation in conferences at the time was considered by a top university manager as 'tourism and little else'. The funding of projects such as the UMCHIP project motivated efforts at the university to support internal and collaborative research projects, the publication of books, the attribution of research grants and participation in international conferences.

In 1994, partly because of his vision and efforts to foster change at the University of Macau, the founder of the AMS-VLSI research group became the dean of FST. In this role, he proposed a new structure for academic careers at the University of Macau, introducing the positions of teaching assistant (bachelor's degree required) and lecturer (master's degree required) to attract the best students and develop a local academic staff. Although this represented an academic inbreeding policy – often considered a nefarious practice in higher education (Horta, 2013) – it was the only viable strategy to build up academic staff, as the University of Macau held little reputation (or financial resources) to attract promising academics from elsewhere. In this case, the academic inbreeding practice was not based on parochialism and nepotism. There were simply no betters from outside the school competing for vacancies. The strategy to downgrade the potential detrimental effects of academic inbreeding involved the definition of an international standard for the completion of engineering degrees. Legislation that regulated master's and doctoral degrees at the University of Macau, which was passed by the Macao government in 1994, was yet another important catalyst for developing research at the university (see Decreto-Lei 15/94/M, 1994). In the 1994/1995 year, with a total of 2785 students, the University of Macau had two students enrolled in PhD programmes and 153 in master's programmes.

A new stress on international quality standards in education led the Portuguese government (at that time still administering the territory), through its Ministry of Education in Portugal, to recognize the University of Macau's engineering bachelor degrees in 1997 (see Despacho Conjunto 49/97, 1997). The same reason led the Technical University of Lisbon to collaborate with the doctoral programmes in engineering at the University of Macau, which granted two dual degrees in 2000 and 2002. These PhD degrees acted as a lever to raise the research and education standards of graduate education at the University of Macau. In the field of microelectronics, the PhD thesis of one of the co-founders of AMS-VLSI in 2002 generated two books, three articles in international journals and 10 articles in conferences, including the top world conference in microelectronics (Institute of Electric and Electronic Engineers [IEEE] International Solid-State Circuits Conference).

Aside from this, the university also developed other areas of knowledge. This happened not only in engineering, but also in Chinese medical sciences (pharmaceutical), leading to the creation of another SKL in 2011, as well as humanities, social sciences and professional disciplines, such as business administration and law.

Since the issuing of the first PhDs by the University of Macau in 1997/1998, the University of Macau has graduated 112 PhDs, 64% in the last four years. In 2013, out of a total of 8971 students, 455 students are enrolled in PhD programs in 2013 (this figure was only 22 in 2002). The growing number of PhD students and graduates led the university to produce 513 journal papers (indexed by the ISI Web of Science) in 2013 alone. For a university that, as a whole, published three articles 20 years ago in a region without any tradition of research, this number represented a quantum leap in the university's knowledge-based development envisioned in the 1992 report. These results were influenced by the founder of the AMS-VLSI research group, as he was elected Vice-Rector for Research at the University of Macau, a position he has occupied since 1997.

AMS-VLSI: from creation to worldwide recognition: management ideas and the impact on university education and research

The changing context of engineering research and education at the University of Macau led in 2003 to the formal creation of AMS-VLSI, as well as to the launch of an IEEE section in Macao (by then the smallest in the world in terms of its members), the world's most relevant professional association in the AMS-VLSI field of research. This field focuses predominantly on the design of analogue front-end interfaces between the digital world of computer chips that deal with '1s' and '0s' (binary codes) and our natural world. Research in this field has undergone significant development in recent years with the emergence of ubiquitous mobile electronic gadgets, such as physical sensors and actuators (e.g. barcode scanners), storage media (e.g. solid-state drives), transmission media (e.g. wireless), imagers and displays (e.g. found in digital photographic cameras) and audio (e.g. sound columns). The policies of the 1990s, focusing on building up graduate education and fostering research activities, enabled the creation of the research group. The increasing availability of local talent and the incentives provided to them to follow an academic career resulted in more qualified local academic staff.

The number of researchers and students participating in the research group increased from one associate professor, three PhD students and six master's students in 2003 to 10 professors, four postdoctoral fellows, 27 doctoral and 16 master's students, and 8 research assistants in 2013. When the founder of AMS-VLSI submitted the UMCHIP proposal to the University of Macau Research Committee in 1994, there were no consolidated research groups at the university, leading the founder to admit that 'it was only me and a Macintosh, nothing else'. In 2003, there were no technicians (essential to any engineering laboratory), nor was there any professional administrative support. Technicians were only beginning to become available a few years later during the evolution of the research group, and only in 2012 was a secretary hired. All of the laboratory's efforts were performed by the academic staff and students. The research group began with a funding amount of roughly €30,000 in 2003 to buy computers and testing equipment, and was set up in a temporary building with one floor (200 m^2) divided into three parts: one for classrooms to support the research component of the master's courses, one for the testing of chips and one for offices. The funding to support research originated solely from the University of Macau budget until 2005, when the Macao Science and Technology Development Fund (FDCT) also began to fund the research group through open competitive projects. The best students would receive a scholarship from the University of Macau Research Committee, which covered their tuition fee and offered them a monthly subsidy.

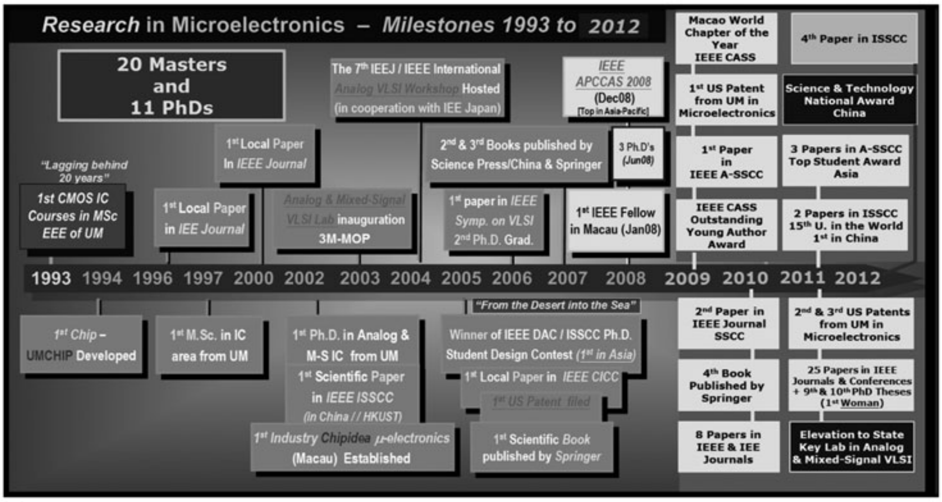
In a little less than 10 years of its existence, starting from a scarcity of financial and human resources, the research group gained nine accepted patents by the US Patent and Trademark Office, published six books and more than 60 articles in international peer-reviewed journals (SCI), and had produced more than 200 international conference papers. One of the group's students attained the first Asian PhD student design contest prize, jointly awarded by the IEEE International Solid-State Circuits Conference and the Design Automation conferences (the top microelectronics conferences in the world), and in 2011, the project of another PhD student was granted the prestigious International Solid-State Circuits Conference Silk Road Award of Region 10 (Asia, Australia and the Pacific) of the IEEE. Most recently, in 2013, a PhD student received the Pre-Doctoral Achievement Award at the IEEE International Solid-State Circuits Conference 2013, held in San Francisco (given for the first time to a student from China). Academics and students of AMS-VLSI were granted 10 national and international awards for project investigators and teachers, 16 R&D awards for graduate students with their supervisors, and 11 undergraduate student R&D awards. In 2007, one of the group's articles was among the top 100 most downloaded articles for three months in the IEEE Circuits and Systems Society magazine.

In January 2011, AMS-VLSI was elevated to SKL of China in Analog and Mixed-Signal VLSI (being the first of its kind in engineering in Macao), enabling it to receive increased funding from the Macao FDCT under the scrutiny of the Ministry of Science and Technology of China (MoST) (see Figure 2). Internally, the SKL was established as an independent academic unit of the university that would be mainly devoted to research. Furthermore, in January 2014, the SKL passed its first three-year mid-term review from the MoST. One of the evaluators from the Chinese Academy of Sciences stated the following: 'we know well the high difficulties that had to be overcome to achieve first-class and world-recognized research results with no first-class students, no first-class research facilities, and no first-class industrial environment'. The most significant evidence of the success of AMS-VLSI is that it positioned the University of Macau as a major player in the world flagship conference of the IEEE International Solid-State Circuits Conference, where approximately 200 articles are accepted annually (100 from companies and 100 from universities). With three papers accepted in 2014 (the first time from an institution in China), the University of Macau became one of the top 10 universities in the world, representing the fourth best in Asia, first in China, and ahead of American universities such as Stanford and Harvard.

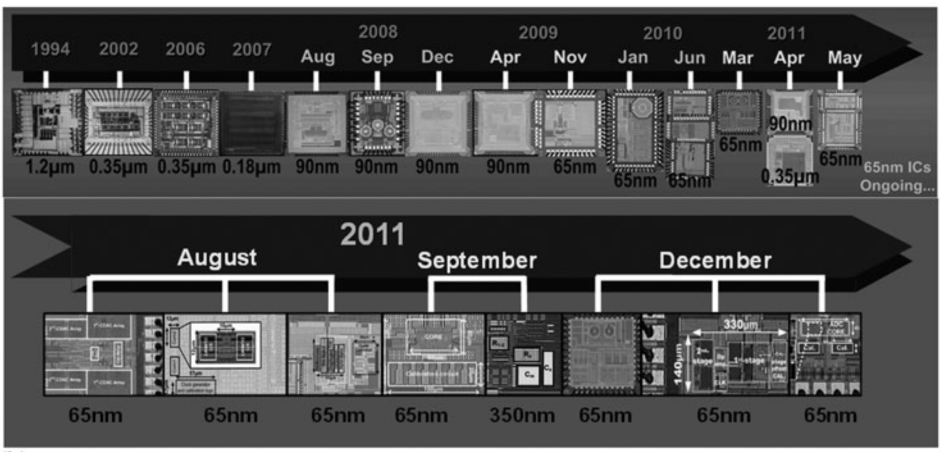
From the interviews, this success can be tied to the following management ideas.

Raise a local human resource base by getting involved in undergraduate teaching

In the 1992 report, the founder of AMS-VLSI noticed that the student body was ready and eager to learn. Two key issues were also identified throughout the 1990s and early 2000s: the university's teaching and curricula were considerably outdated, and its research activities were limited to the FST. The academic staff during most of this period comprised full-time academics teaching outdated knowledge, part-time academics from local utility companies (e.g. electricity and telecommunications) and a few young lecturers from Portugal. This was a teaching staff that performed no research. The dean of the FST and founder of AMS-VLSI could not risk the organizational instability of



(a) Research and teaching outputs/milestones



(b) Chip prototypes resulting from Master and PhD theses

Figure 2. Evolution and main achievements of AMS-VLSI (adapted from Martins, 2012).

dismissing full-time academics (they gradually retired), and therefore part-time academics were replaced by higher-qualified and more research-oriented young academic staff. This process took time, as there were few conditions available to attract promising academics from abroad.

In this context, the strategy to raise local promising human resources was to identify talent among the university's engineering students during the early stages of their studies, establish an academic/learning relationship with them and teach them the core knowledge of any good engineering degree: mathematics applied to electrical engineering and basic state-of-the-art electronics. A strong applied mathematical basis is critical to an engineering student, because it provides the basic cognitive tools to learn more advanced knowledge in the field. Taking this into account, leaders of research groups may need to immerse themselves in teaching at the undergraduate level to develop a future core of research groups. Establishing relations with promising students from their beginnings at a university creates trusting relationships that can be further developed in graduate education, if students decide to pursue it. A quote from an interview with the research group founder is illustrative of these points:

> I pick up the students in the first year. Courses I have never taught in Portugal but basic mathematics and circuits' knowledge are necessary for electronics … I started to know them in the first year and then we were able to get some of them in the final bachelor's project. And then they followed into a master's with us.

Recruitment: academic inbreeding (with a twist)

Raising local human resources and restructuring academic careers at the University of Macau in 1994 fostered the implementation of academic inbreeding, a practice often recognized as detrimental to academic research, typically when high academic inbreeding rates are present. However, such a practice can also bring fast growth to a university's knowledge base and institutional identity during its early stages of development (Horta, Sato, & Yonezawa, 2011). For the University of Macau, inbreeding was deemed the only possible strategy to create qualified academic staff, as the university did not have the reputation or financial resources to attract promising or established scholars from other parts of the world, and, as the research flagship of a small higher education system, recruitment from other universities in Macao was not a solution.

Academic inbreeding practices were implemented at the university so as to avoid two of its negative characteristics: nepotism, the selection of in-house university candidates over outsiders who may be of better quality; and parochialism, valuing knowledge within the institution over outsider knowledge. With regard to the former, despite the lack of outside competition for positions at the university, the university's in-house candidates were of high quality. For example, the first master's thesis in microelectronics completed at the University of Macau yielded six published articles: two in journals and four in IEEE conferences. During his PhD degree, the same student produced a journal article, two IEEE international conference articles, a chip, a book published by Springer and a thesis that was chosen by China's Science Academic Press for a selected publication. Following his degree, the student was hired by the University of Macau, where aside from co-founding AMS-VLSI, he also co-founded the first company devoted to advanced analogue and mixed-signal semiconductor intellectual property product development in the territory, published roughly 70 articles and received several prizes and awards, including the Most Favourite Teacher at the University of Macau for two consecutive years and the Scientific and Technological Innovation prize in 2010.

To avoid the pitfalls of parochialism, many of the university's students visited other universities abroad during their education, with some engaging postdoctoral efforts. These they deemed as decisive in orienting their research agendas, as was the case for one AMS-VLSI research line coordinator who spent several months at the University of Cambridge:

> As an electric engineer, I studied here [University of Macau], but the field is too narrow. If you want to continue your development, you need to think 10 years into the future of electronics. You try to gain knowledge of biomedical, science and physics developments … You go to their laboratory [in Cambridge] and see what they are looking for … [Travelling] offers the chance to physically talk and look at those things that you cannot experience otherwise.

Stressing and maintaining quality with measurable standards

The need to develop quality output from all activities that academics and universities undertake has become a common goal of management and policy-making within higher education. In the case of AMS-VLSI and the FST, such a stress on quality was made with clear measurable targets. The establishment of new standards for undergraduate and graduate education initially faced strong opposition at the university, though this was overcome through the strong performance of several of the most promising students at the university, who in turn became part of the school's academic staff. In the FST, the rule for bachelor's students completing their final projects was that they could be involved in international conference papers. Those completing their master's theses were required at least to publish a conference paper in an international conference, and PhD students were required to publish one or two conference articles and one journal article in a top IEEE journal to be granted their degree. The opposition to these rules was due to the belief that the standards had been set too high. However, the establishment of these standards created a measurable target for the university's students to work toward, which gave them greater focus.

Currently at the FST, these standards are now well-established norms, and the university's students continue to drive these standards to higher levels. The founder of AMS-VLSI states:

> they [two research line coordinators] exceeded [the school's standards] significantly, even patents and books came out from their work and others followed up … but then this went very high because they went to a top conference, IEEE International Solid-State Circuits Conference, and now everyone wants to publish there, which is extremely difficult.

The university's quality standards help to explain why its students became strong candidates to work there, as well as the university's strong academic routines and publications. A research line coordinator at the university states the following in this regard:

> I do not know why I published this book, or publish so much. We just literally do all of these steps maybe due to the high standards imposed by our supervisor, and we do not know an alternative. We just follow.

It is relevant to note that, in terms of graduate education in microelectronics, the university developed a rather unusual output: microchips. The theses of the initial master's and PhD students would not merely deliver knowledge to the field in the form of articles and books, but lead to the design of a chip that would then be tested in terms of speed, reliability and other key characteristics. With the potential to be applied to people's daily lives, this output shaped the working objectives of the university's students and how they were to learn. This also reinforces the importance of and the need for constant involvement of the research leaders and faculty in research and teaching activities. As dean of the FST and vice-rector of the University of Macau, the founder of AMS-VLSI maintained his involvement in teaching, research and mentoring graduate students within the university, and this involvement emphasized to the entire research group and university the importance of sustaining ongoing linkages between academic management, research and teaching activities.

Departing from loose organizational structures: voluntarism and the freedom to develop scientific agendas

That the research group structure was built from the ground up without defined research lines during its initial stages was considered important for the establishment of a creative environment. The main research lines that structured the organization of the research group (data conversion, signal processing and wireless) resulted from the interests of its first doctorates. These areas were then progressively defined by the then doctorate students and academic staff of the research group. The research group was created with an ad hoc structure, because in the beginning, as one group member stated, ‘one could not predict too much. [You had to] work out one step, then take another step, one by one’. The underlying idea was that the conditions did not yet exist to conceive of and establish a field of specialization. These conditions did not concern only financial and human resources, but also a defined idea as to what the strategic agenda of the group could be. As the interviewees stressed, a major benefit of this ground-up approach during the early stages of development was that, aside from establishing a creative environment, it mitigated the failures of specific ideas and projects until a solid project could be found and developed. The development of doctoral research and the establishment of AMS-VLSI’s structure went hand-in-hand from the very inception of the research group.

It would be around the initial PhD projects that the research lines of AMS-VLSI would materialize and its research teams consolidate (see Rey-Rocha et al., 2006). The recent doctorates of the group that developed these lines then became their coordinators and further developed them together with students. In this process, two factors were quite important: voluntarism and size. The research group started with no support staff, with ‘everything … built by the students’, as one research line manager reported. This voluntarism, while burdensome in terms of energy and time, gave the then students a strong sense of identity with the research group and ultimately with the university. It created an environment of well-being known to be critical for research productivity (Torrisi, 2013), occurring at a particularly important moment in their academic careers: during their PhD. That the interviewees associate their individual successes with the organizational success of the research group evidences how a sense of belonging and well-being drives motivation to grow as a group. A quote from one of the interviewees illustrates this point: ‘That is why we are really strong and tough. We built everything from scratch’. Today, the work of researchers and students within the group is supported by technicians, which allows for more time to focus on research alone. However, the organizational identity of the group continues to be bolstered by the management of the research group.

The growth of the research team in terms of its number of researchers and research agendas took roughly five years. In the beginning, the group’s ad hoc organization was partly due to its small size. However, as research lines consolidated, the team grew in size, and as the research group gained greater visibility, its research incorporated new lines of interest in biomedicine and chemistry. These were led by researchers hired from outside the University of Macau, which represented a decisive change in recruitment focus to develop the size of the research group. Strong specialization during AMS-VLSI’s initial stages was critical to foster the development and critical mass necessary for the two new research lines. Only after this was achieved could a broader array of fields be explored, as stated by one research line coordinator:

> We have a new area emerging, microfluidics, that we did not have any clue at all about until a professor came here for a lecture. We found it interesting. We did not know what to do, but then we invited a chemistry researcher who joined the lab as a Ph.D. student, and … she basically started up the area. It basically merges chemistry, biology and electronics.

Conclusion

The above analysis explains how a research group attained worldwide recognition and details how its development influenced research and teaching in a developing university characterized by scarce investment in knowledge and human resources. In terms of the impact on teaching, the establishment of standards of measurable quality at the university raised the bar both for graduate students in the FST and for researchers working within AMS-VLSI.

This impact was lesser for undergraduate education, but the involvement of research leaders in it was critical for the identification and development of the most promising students at the school. The high determination, international exposure and quality of these promising students enabled them to be hired by the university. The practice of academic inbreeding at the university was its sole solution to the difficulty of attracting outside academics to the University of Macau, yet this practice was twisted to avoid the two most nefarious characteristics of academic inbreeding: nepotism and parochialism. The practice allowed for the creation of an initial critical mass that would be devoted to the university and develop its research reputation to attract promising scholars from other regions of the world in the future (recently hired academics are already being recruited from outside the university). Inbreeding allowed for a research group to be developed from the ground up at the university and expand into diversified fields of research.

In addition to this, the roles of internationalization and leadership at the university were key. International exposure is essential to any university today (Pfotenhauer et al., 2013). The University of Macau's standards for the completion of a master's or PhD degree relate to international conferences, publications and prizes. International mobility and exposure are understood as essential during the formative years and throughout one's academic career. The leadership of the founder of AMS-VLSI, dean of the FST and later vice-rector allowed for changes and policies to be implemented faster and with institutional support at the university. His international links, predominantly with his former university in Portugal, were essential to the launch of microelectronics research at the University of Macau. In a competitive academic global world, it is commonly accepted that established academics should be hired and followed, yet the case presented in this article suggests that younger academics with vision, drive and solid research records can represent a major driving force for institutional change and improvement (see Goodall, 2009).

Funding

This work was financially supported by a research grant from the University of Macau.

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