Consultant Report

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STEM: Country Comparisons

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Report of Taiwan: STEM (Science, Technology, Engineering and Mathematics)

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Introduction

Located in the Pacific Ocean about 160 kilometers across the Taiwan Straits from Mainland China, Taiwan is an island region where Confucian-heritage culture remains. Over the past 60 years, Taiwan has changed from a net importer dealing primarily in agricultural products, to a leading exporter of industrial products, such as machinery and electrical equipment. The advancement of science and technology has driven the massive development of the economy in Taiwan; therefore, sci-tech education is placed as a priority in Taiwan's school system (Da Hsuan, 2006; Ku & Lee, 2001; Lee & Lin, 2012). Particularly, maintaining a competitive edge within the 21st century depends on the cultivation of human capital, producing qualified and innovative employees capable of competing within the new global marketplace. In the knowledge economy, sci-tech plays an even more significant role in worldwide competition, therefore, the Taiwan authorities need to sustain the increase in sci-tech investment and then improve the science literacy of all citizens, training sci-tech talents and enhancing national competitiveness.

In the Taiwanese context, science education is part of the 'education for all' mission, which covers the range of all citizens. It emphasizes the development of science literacy, individual creativity and innovative ability. In the first National Science Education Conference in 2002, the goals of science education in Taiwan were stated as

> enabling every citizen take delight in learning science and understand the application of science, be curious about the profoundness of science and appreciate the beauty of science (MoE & NSC, 2003, p. 7).

These goals could be interpreted from three aspects: first, these goals require that science education should be rooted in everyday life and culture; second, science education should enable the citizen to use scientific methods and knowledge to solve the problems encountered within daily life and to criticize social problems rationally and then to make proper decisions; third, science education is required to improve citizens' science literacy, in order to make a contribution to the world economic growth and sustainable development (MoE & NSC, 2003). From the proposed goals of science education, it can be seen that the focus of science education in Taiwan has transformed from the cultivation of scientists in 1990s to 'science for all' and the ultimate purposes of science education are to pursue the welfare of all human beings rather than merely facilitating economic or technological development (Z.-W. Chen, 2009; Xiong & Chen, 2006; Zeng, 2007). The concerns about humanity have been put in a prior place in Taiwan's science education.

Through scientific research, science education enables the students to gain relevant knowledge and skills, cultivate scientific thinking and methods, use sci-tech knowledge and skills to find solutions; finally, perceive the nature of science and foster scientific spirit and attitude. During the process, students' creativity and innovative ability could be developed with the concerns about humanity (MoE & NSC, 2003). Thus, science education in Taiwan consists of three components: training scientific research capacity and skills; acquiring science-related knowledge and concepts and fostering of scientific attitude.

In this report, an overview of the STEM system in Taiwan is provided through four parts of elaboration: the overall landscape of STEM in Taiwan, STEM in primary and secondary education, STEM in higher education (HE) and STEM personnel and employment. The relevant policies will be analyzed, the participation of students in STEM at different level education will be examined and the strategies for boosting STEM in Taiwan will be discussed as well.

Overview of the STEM system in Taiwan

Evolution of Taiwan's STEM-related policy and system

Since the 1950s, the Taiwan authorities have issued a series of sci-tech development policies and strategies. These policies had led to spectacular technical achievements and had greatly promoted Taiwan's advance in technology and economy. Because of the dramatic economic prosperity of Taiwan since 1970s, it has been known as one of the 'Four Asian Tigers'. The flourish of economy in Taiwan is closely related to the sci-tech development (S. Chen & Zhang, 2007; Du, 2011; Jiang, 2012). The aim of sci-tech policies is to transform sci-tech achievements into productivity by exerting national or regional political and economic power, finally fulfilling the missions of national, economic and social development (B.-K. Wu, 1998).

The sci-tech policies have evolved in accordance with the different demands of economic development in Taiwan, which could be divided into three major stages. First, from 1950 to 1960, the focus of sci-tech policies was the importation of advanced techniques and the transformation of traditional techniques. In the early 1950s, the economy in Taiwan was underdeveloped and the authorities faced severe problems such as the lack of food, backward industries and insufficient foreign exchanges. Accordingly, the sci-tech policies addressed the economic needs, focusing on importing advanced techniques and transforming the traditional techniques. In 1959, the first *Long-Term National Science and Technology Plan* was issued, meanwhile, the National Long-Term Science Development Committee was established, which was responsible for promoting science development. The imported techniques resulted in the rapid economic blossom (Cai, 2007; S. Chen & Zhang, 2007).

From 1970 to 1980, the focus of Taiwan's science policies moved to a combination of technique importation and indigenous R&D for the purpose of technology upgrade. During the decade, the emphasis of sci-tech policies was not only on technique importation but also on R&D in various industries. The authorities launched the *Twelve Years National Science and Technology Development Plan (1969~1980)* and established the Industrial Technology Research Institute. They also provided funds for enterprises to improve their techniques. At the same time, the authorities issued the first professional training regulation—*Professional Training Golden Regulations*, in order to strengthen the science manpower cultivation. Since the 1980s, the sci-tech policies intended to facilitate the upgrading of industrial structure, from labor and capital intensive to technology intensive industries (ibid). In this period, the economy in Taiwan expanded to full speed.

Since the 1990s, against the context of increasing globalization, the competition in the sci-tech innovation has become extremely fierce worldwide. Most countries and regions adjusted their economic strategies and sci-tech policies. The Taiwan authorities actively responded to the new demand of development and put the high-tech industry at the center of sci-tech development with the vision of making Taiwan as the Green Silicon Island. Ten new-emerging industries have been regarded as strategic priorities and science parks have also been established for boosting the cooperation between universities, research institutions (RIs) and industries (S. Chen & Zhang, 2007; Y. Wang, 2012).

Over time this series of policies have laid down a crucial institutional foundation that interdependent agencies for S&T development have been established at all levels, constituting an effective science system in Taiwan (see Fig.1). Taiwan's S&T system can be divided into promoting, implementing and assessing organizations. The S&T promoting organizations include the National Science Council (NSC), Science and Technology Advisory Group (STAG) and other science-related ministries, such as the Ministry of the Interior, Ministry of National Defense, Ministry of Education, Ministry of Economic Affairs, Department of Health, etc. (NSC, 2010).

S&T implementing organizations mainly consist of actors involved in the four aspects of basic research, applied research, S&T development, and commercialization. The chief implementing organizations for basic and applied research are the Academic Sinica and domestic universities and colleges. The chief implementing organizations for applied research and S&T development are non-profit RIs and higher education institutions (HEIs). Commercialization is chiefly implemented by public and private enterprises.

The S&T assessment system includes the stages of S&T project review, implementation control, and results evaluation. The review stage emphasizes the drafting of focal projects. Control and evaluation are performed during project/program implementation, and results and review opinions provide a basis for project revision in a feedback process (Cai, 2007; NSC, 2010). In order to enhance the efficiency of administrative agencies, the government has embarked on a campaign to restructure the S&T organizational system. In the future, a Ministry of S&T will be established to develop S&T policies, implement major S&T R&D research programs and control the funding budget for basic scientific and applied S&T research (NSC, 2010).

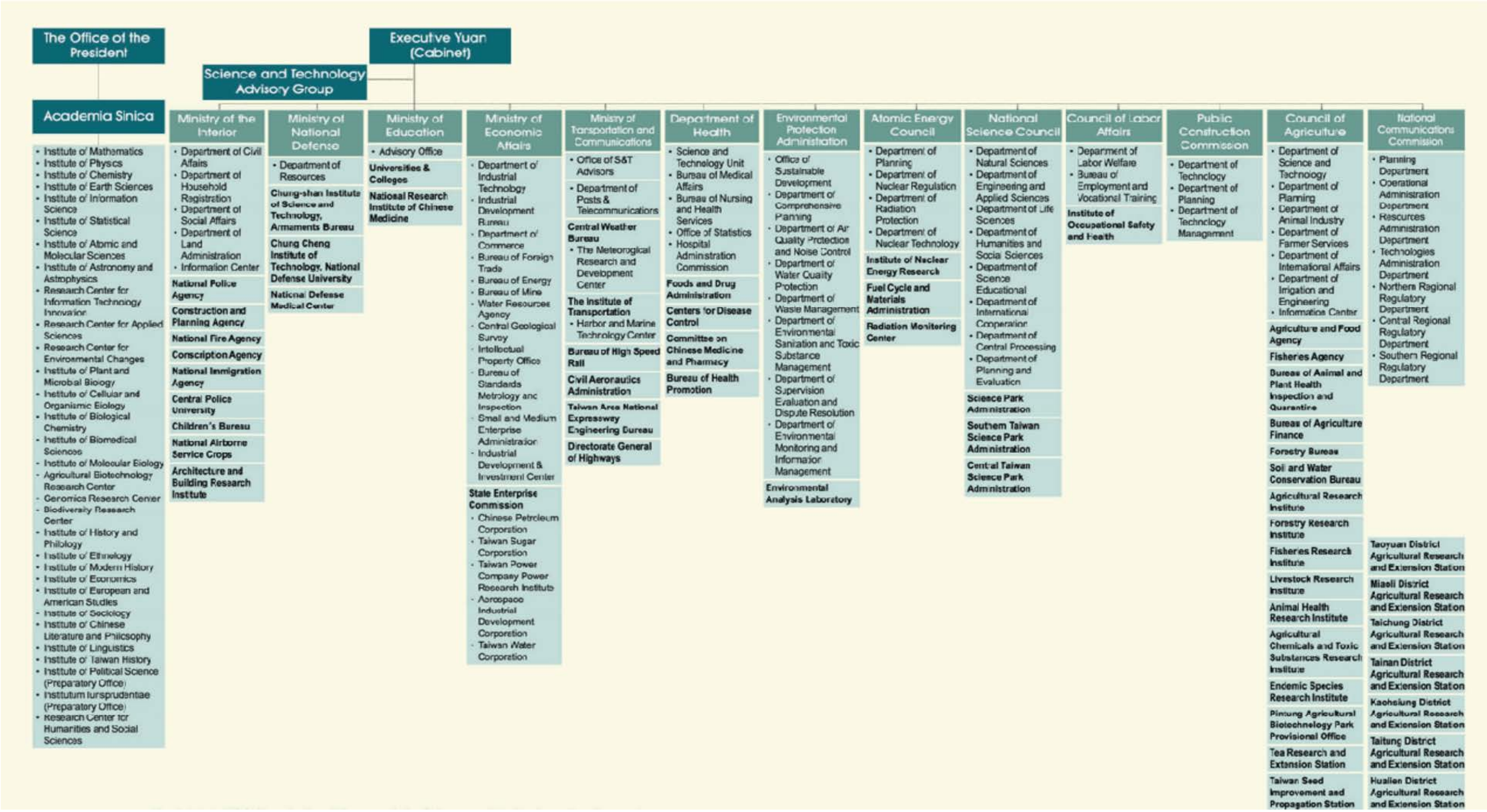


Fig.1 S&T System in Taiwan

(Source: NSC, 2010, p. 7)

STEM in the national interest

The development of S&T drives national and regional development. For a region like Taiwan with extremely limited resources, the development of S&T is particularly crucial since only with advanced S&T can the transformation of the economic structure can be realized, the competitive products be produced and the advantage in economic competition be obtained. The heavily populated island of Taiwan possesses a unique landscape. Resources are limited, natural disasters such as typhoons; torrential rains and earthquakes are common. Apart from a fragile natural environment, Taiwan also faces urgent problems such as an aging society, the trend toward smaller families and the concerns of safe living conditions (NSC, 2009, 2010; P. Wang, 2006; Z.-C. Wang & Yang, 2008). In order to address the above challenges and to keep pace with today's knowledge economy and globalization trends, the Taiwan government places increasing emphasis on the R&D of innovative technology, the maintenance of a green, sustainable environment, the promotion of industrial and economic development, and the enhancement of citizens' welfare. Beyond continuing to rely on the strengths of the information and communications industry, the Taiwan authorities have also taken active measures to develop green energy and smart living technology, strengthen biotech medicine and disaster mitigation and response R&D, promote dialogue between technology and humanities, aiming at transforming Taiwan into a global leader in green energy technology and intelligent living (NSC, 2009, 2010).

In light of the fact that S&T and innovation play a decisive role in national competitiveness, the government has steadily increased the national investment in S&T. Table 1 shows the gross expenditure on sci-tech R&D (GERD) in Taiwan from 2006 to 2011[1]. The average growth rate was 6.65 percent in the six-year span. R&D expenditure grew by 4.6 percent in 2011, which was less than the average growth rate. Taiwan's R&D expenditure as a percentage of GDP (R&D intensity) increased steadily from 2.51 percent in 2006, and reached 2.94 percent in 2009. With the global recovery in 2010, Taiwan's economic growth rate of 10.8 percentage set a new high for the past decade, and the nominal GDP growth rate reached 8.6 percent. However, because the GERD growth rate of 7.6 percent was less than the GDP growth rate, R&D intensity dropped by a very slight 0.03 percent in 2010 compared with 2009. Moreover, due to the European debt crisis, most countries experienced poor economic conditions in 2011, and Taiwan's nominal GDP was only 0.9 percent growth for the year. Since in 2011 the GERD grew at a higher rate than the nominal GDP, R&D intensity in 2011 reached 3.02 percent, surpassing 3 percent for the first time (Table 2). According to the OECD (2011a) figures, Taiwan ranked 10th in GERD, and in terms of R&D intensity, in 2009 Taiwan's expenditure on R&D took up 2.94 percent of GDP, ahead of the average of OECD members (2.3%).

[1] In the sections followed, all the data without specific note are sourced from (NSC, 2012), and the tables and figures in this section are summarized by the author according to the data.

Table 1 GERD in Taiwan (2006~2011)

	2006	2007	2008	2009	2010	2011
GERD (Million NT$)	307,037	331,386	351,405	367,174	394,960	413,293

Table 2 GDP and R&D Intensity in Taiwan (2006~2011)

	2006	2007	2008	2009	2010	2011
GDP (Million NT$)	12,243,471	12,910,511	12,620,150	12,481,093	13,552,099	13,674,346
R&D Intensity (Per cent)	2.51	2.57	2.78	2.94	2.91	3.02

Fig.2 presents the relative expenditure of different types of R&D in Taiwan during the last six years. Expenditure on experimental research rose from NT$ 194.5 billion in 2006 to NT$275.2 billion in 2011, and accounted for 63.4 percent to 66.6 percent of overall R&D expenditure. Experimental research is the fastest growing type of R&D in Taiwan. Applied research expenditure increased from NT$ 81.3 billion in 2006 to NT$97.94 billion in 2011, taking up 23.7 percent to 26.5 percent of overall expenditure. Basic research expenditure grew from NT$ 31.2 billion in 2006 to NT$40.18 billion in 2011. Its share of overall expenditure was maintained at approximately 10 percent. In general, the proportion of R&D expenditure on experimental research increased by 3.2 percent in the six years, while the expenditure on applied research dropped 2.8 percent. The proportion of expenditure on basic research remained during the same period with slight fluctuations. Compared with the situation in Mainland China, Taiwan's expenditure structure is more balanced, similar to the pattern in most developed countries. Unlike Mainland China, basic research had been paid reasonable attention in Taiwan, accounting for 10 percent of overall expenditure. According to Fig.3, 59.4 percent of basic research expenditure was implemented by the HE sector in 2011, followed by the government sector (36.6 percent), and only 3.2 percent was implemented by the business sector. In both applied and experimental research, the business sector was the biggest performer, implementing 60.8 percent and 87.0 percent of the two types of research respectively in 2011. This is different from the situation in Mainland China where the HE sector contributes more in applied research.

Among the total GERD in 2011, 72.5 percent came from the business sector, and the government and HE sectors contributed 26.2 and 0.9 percent separately (Fig.4). The distribution of investment among different sectors shows that enterprise has become the principal force of R&D activities; however, the role of HEIs in sci-tech investment needs to be strengthened in the future. Only less than 1 percent funds came from the HE sector.

Fig.2 R&D Expenditure by Type of R&D in Taiwan (2006~2011)

Fig.3 R&D Expenditure by Type of R&D and Sector of Performance in Taiwan (2011)

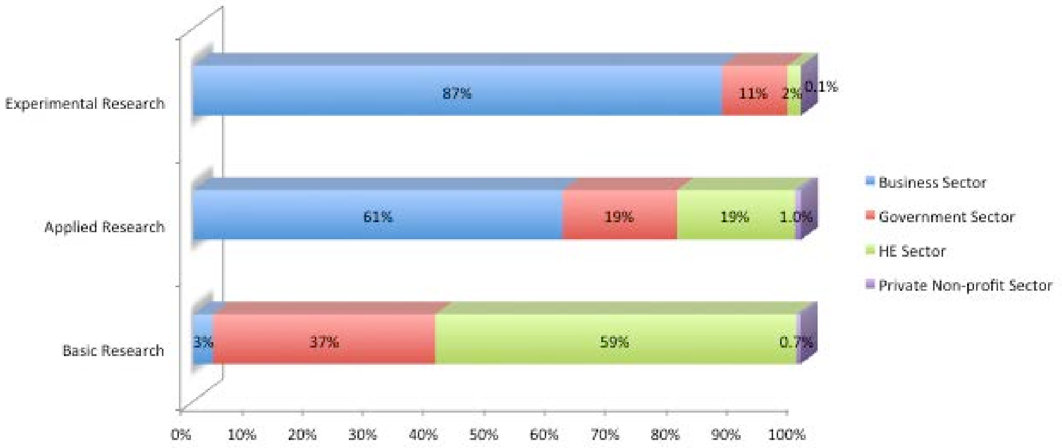
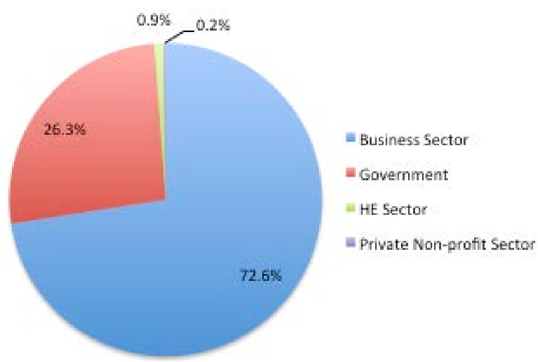


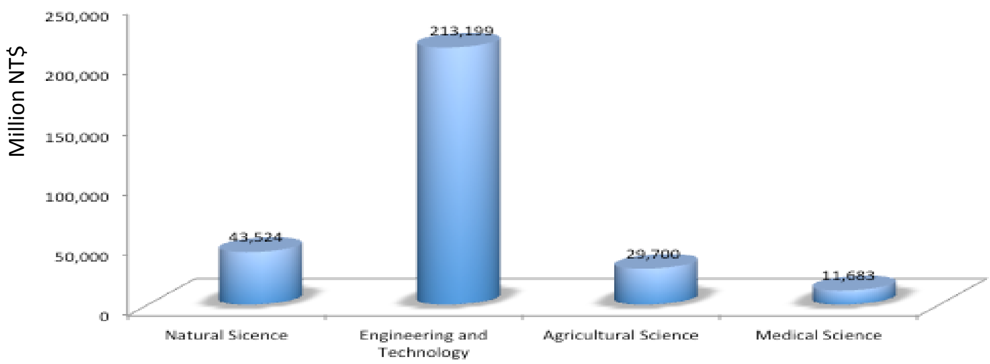
Fig. 4 GERD by source of funds in Taiwan (2011)

Source of Funds	Total (Million NT$)
Business Sector	299,755
Government	108,464
HE Sector	3,918
Private Non-profit	1,007
Total	413,114



In 2011 the total GERD summed across all sectors varied markedly according to the field of S&T research (see Fig.5). The priority of R&D investment was Engineering and Technology, which received NT$312,199 million, followed by Natural Science (NT$43,524 million). The total GERD on Agriculture and Medical Sciences was NT$11,683 billion and NT$29,700 billion respectively. The pattern is similar to that of Mainland China.

Fig. 4 GERD by field of research



STEM in the business sector

One of the most urgent problems faced by Taiwan is how, in the face of intense international competition and economic and environmental changes, it can build on its existing advantages and strengthen its capabilities for better performing in the new globalized world (Dai, 2007; Lin, 2009; P. Wang, 2006). It is certain that industry has to actively develop appropriate strategies in order to enhance its technological expertise if it intends to be upgraded to the next stage of high-tech development and create new opportunities for sustaining Taiwan's economic growth. Enhancing the sci-tech innovation system and forging links with international R&D resources will enable industry to leverage domestic and overseas R&D capacities (Dai, 2007; Jiang, 2012; X.-J. Zhang & Liu, 2012). In addition, interdisciplinary, integrated technologies and applications can be used to provide innovative services and added value. Enterprises in Taiwan and abroad are highly concerned with their innovation ability, which is seen as a key element maintaining the competitive advantage and continued growth. How to provide a superior environment for industry development and facilitate enterprises' motivation and capacity to innovate is a major concern in Taiwan's current industrial development strategy (Du, 2011; NSC, 2009; Y. Wang, 2012).

The business sector is the biggest part of both R&D funding source and R&D expenditure performer. The investment of the business sector in R&D grew at an average rate of 7.8 percent from NT$ 206.2 billion in 2006 to NT$ 299.8 billion in 2011. The business sector's R&D funding as a share of industrial added value grew from 2.3 percent in 2006 to 2.96 percent in 2011, which shows increasing emphasis on R&D placed by Taiwan's enterprises. In regard to the cost items, the most significant change was labor costs, which grew at an average rate of 10.4 percent over the past six years. In 2008, labor costs as a share of business sector R&D expenditure even exceeded 50 percent. The larger share of labor costs is due to the fact that manpower is the most important asset for enterprises' R&D. Enterprises not only increased the number of R&D personnel, but also employed more R&D personnel with higher research degrees. Because of the intensive competition for R&D manpower, domestic companies have been relying on soaring bonuses and profit sharing to retain high quality manpower. This is an important reason why

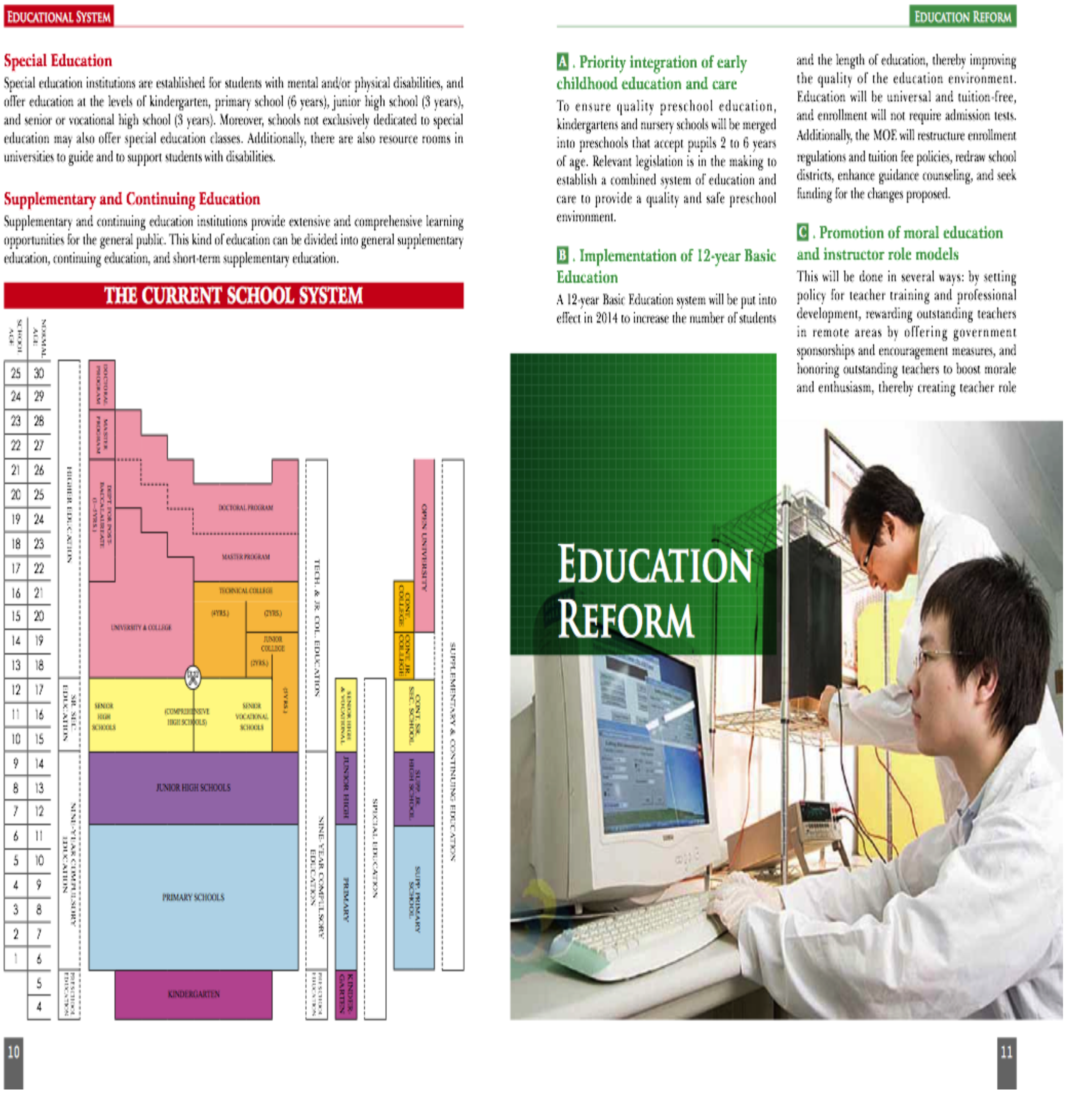
R&D labor costs and overall expenditure of business sector have been increasing (NSC, 2010, 2012). Looking at R&D expenditure in industries with different technology intensities, Taiwan's high-tech industries had the greatest R&D expenditure during the last six years. In 2011, it accounted for 75 percent of the overall business sector's expenditure on R&D. In terms of type of industry, most business R&D funding went to manufacturing industry, which took up 92.88 percent of the whole (NSC, 2012).

STEM in the education sector

In Taiwan, students' STEM capacity is built via a comprehensive and diversified school system. There are six years of primary school education followed by three years of junior secondary education. Compulsory education ends following a student's 9th grade year and Taiwan allows transitions between many of their vocational and academic tracks in the following stages. The figure following gives a general summary of the education system structure in Taiwan. According to the *National Education 9-Year Curriculum Outline (2008 edition)*, during the compulsory education period, science education in Taiwan is divided into two parts: mathematics and nature & life sci-tech. Unlike the situation in Mainland China where science is taught in separate subjects (physics, chemistry and mathematics) in junior secondary schools, the science learning is more combined and integrated in Taiwan. Nature & life sci-tech discipline area include the knowledge about materials and energy, life science, earth and environment, ecosystem and information technology (MoE, 2008a). Compared with the science subjects taught in Chinese junior secondary schools, the science curriculum in Taiwan involves a wider range of science-related topics but the requirement and depth of each topic are less demanding than the counterpart in Mainland China.

Junior secondary school diplomas are granted based on credit and/or grades in Taiwan, and there is no formal graduation test. Students need to attend Junior Secondary Basic Competence Test in order to continue their study in one of three tracks: 3-year senior secondary school (the traditional academic track, which offers students the most opportunities towards university admission), 3-year senior vocational school (which allows students to test into university) as well as a 5-year technical college track, during which students generally do not test into university. In 2006, a new type called comprehensive senior high school was introduced to the secondary education system in Taiwan, which allows students to enter university or technical college for study after graduation. In 2011, the ratio between the number of senior secondary students and the number of senior vocational students was about 52:48.

Fig.5 The Current Education System in Taiwan


EDUCATIONAL SYSTEM

Special Education

Special education institutions are established for students with mental and/or physical disabilities, and offer education at the levels of kindergarten, primary school (6 years), junior high school (3 years), and senior or vocational high school (3 years). Moreover, schools not exclusively dedicated to special education may also offer special education classes. Additionally, there are also resource rooms in universities to guide and to support students with disabilities.

Supplementary and Continuing Education

Supplementary and continuing education institutions provide extensive and comprehensive learning opportunities for the general public. This kind of education can be divided into general supplementary education, continuing education, and short-term supplementary education.

THE CURRENT SCHOOL SYSTEM

EDUCATION REFORM

A. Priority integration of early childhood education and care

To ensure quality preschool education, kindergartens and nursery schools will be merged into preschools that accept pupils 2 to 6 years of age. Relevant legislation is in the making to establish a combined system of education and care to provide a quality and safe preschool environment.

B. Implementation of 12-year Basic Education

A 12-year Basic Education system will be put into effect in 2014 to increase the number of students and the length of education, thereby improving the quality of the education environment. Education will be universal and tuition-free, and enrollment will not require admission tests. Additionally, the MOE will restructure enrollment regulations and tuition fee policies, redraw school districts, enhance guidance counseling, and seek funding for the changes proposed.

C. Promotion of moral education and instructor role models

This will be done in several ways: by setting policy for teacher training and professional development, rewarding outstanding teachers in remote areas by offering government sponsorships and encouragement measures, and honoring outstanding teachers to boost morale and enthusiasm, thereby creating teacher role

10 11

(Source: MoE, 2012, p. 10)[2]

Taiwan offers two types of university entrance tests: the 5-subject General Scholastic Ability Test (GSAT) which covers Chinese, English, Mathematics, Social Science and Natural Science; and the University Entrance Exam/Department Required Subject Tests, which offers ten subjects: Chinese, English, Math A, Math B, Physics, Chemistry, Biology, History, Geography and Social Studies. Students from senior and comprehensive secondary schools are eligible for both of the two tests. Students who have graduated from vocational secondary schools can also attend the Department Required Subject Tests to pursue HE. Students studying in senior secondary schools in Taiwan are required to choose their track from Natural Science and Social Science in 11th grade, one year later than their counterparts in Mainland China. It means science-related subjects are taught compulsorily in Taiwan in an 11-year period, which allows students to have a solid

[2] In the sections followed, all the data without specific note are sourced from (MoE, 2012), and the tables and figures in this section are summarized by the author according to the data.

foundation of mathematics and science knowledge and skills. Another difference between Mainland China and Taiwan in terms of science subject teaching is the coverage of science learning. In Taiwan, students who choose the Natural Science track need to learn four subjects: physics, chemistry, biology and earth science, one more than their Chinese counterparts. Earth science, as a separate subject, is taught in Taiwan's senior secondary schools. And differentiated secondary school options, including comprehensive secondary school, vocational high school and technical colleges and programs beginning shortly after junior secondary school produce a greater number of alternatives for producing STEM capable students in Taiwan.

Students enter HEIs after completing senior or vocational secondary study. HEIs are a key element of the national science and innovation system. They bear the responsibilities of cultivating sci-tech manpower and they are directly involved with sci-tech research activities. The HE sector's R&D expenditure grew steadily at an average rate of 4.9 percent between 2007 and 2011. The major source of funds came from government investment. During the last five years, the share of HE R&D expenditure derived from business sector sources has been in the range of 5.3 to 7.5 percent, and this percentage has been increasing steadily, which could be attributed to the improved industry-academic collaboration. Universities' R&D capabilities boost the quality and quantity of business sector R&D outcomes, increase the practical value of academic research, and enhance the competitiveness of Taiwan's industry. In 2011, 35,818 full-time equivalent (FTE) research people were involved in sci-tech work in HEIs, accounted for 16.2 percent of total R&D personnel (FTE) in Taiwan and HE sector spent 11.9 percent of GERD in 2011 (NSC, 2012).

In 2011, the number of enrolments in Bachelor Courses in Taiwan was 1,250,784, among them, the number of students participating in STEM-related fields reached 532,418, taking up 52.57 per cent of total enrolments (see Fig.6). Similar to the situation in Mainland China, engineering is the most popular discipline, followed by medicine and science. For postgraduate study in Taiwan, HEIs provide Master and Doctoral courses, and only one type of Master program is offered with requirements for coursework. The total enrolments of postgraduate courses in 2011 was 217,799, among them, 106,215 majored in STEM-related fields (Fig.7). From the data, it could be seen that compared with Humanity and Social Science studies, science-related majors had the largest participation proportion at all levels of programs in Taiwan.

Fig.6 Enrolment in Bachelor Courses by field of education in Taiwan (2011)

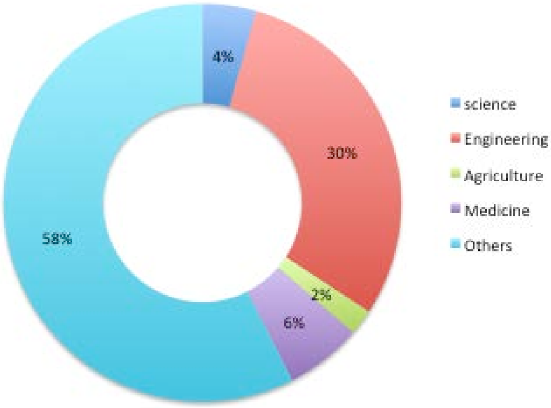
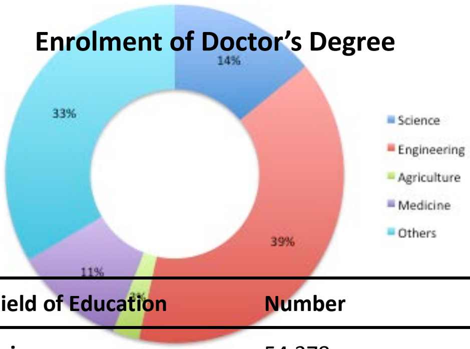


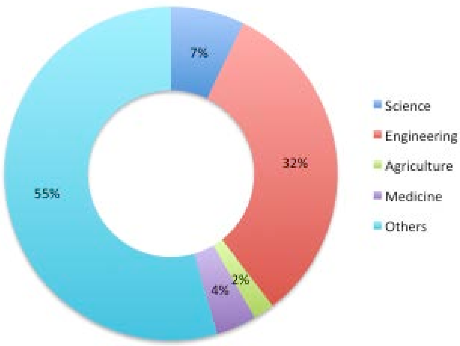
Fig.7 Enrolment of Master and Doctor’s Degree by field of education in Taiwan (2011)

Field of Education	Doctor’s Degree	Master’s Degree
Science	4,745	13,221
Engineering	13,248	59,575
Agriculture	867	3,758
Medicine	3,563	7,285
Others	11,273	100,274
Total	33,686	184,113

Enrolment of Doctor’s Degree



Enrolment of Master’s Degree



Field of Education	Number
Science	54,378
Engineering	373,827
Agriculture	26,125
Medicine	78,088
Others	718,366
Total	1,250,784

STEM in primary and secondary schools

Taiwan's primary and secondary science education aims at improving every student's research ability, creativity and critical thinking, and cultivating students' curiosity and scientific ethics and attitude (MoE & NSC, 2003). Science education is much more than just knowledge about S&T and their application. It involves educational programs where learners become engaged in critical thinking as they design and develop products, systems, and environments to solve practical problems (Wong, Yang, & Fong, 2002). In order to fulfill the aims of science education at primary and secondary level, MoE has reformed the curriculum for several times to expand students' participation in STEM and to improve students' science literacy.

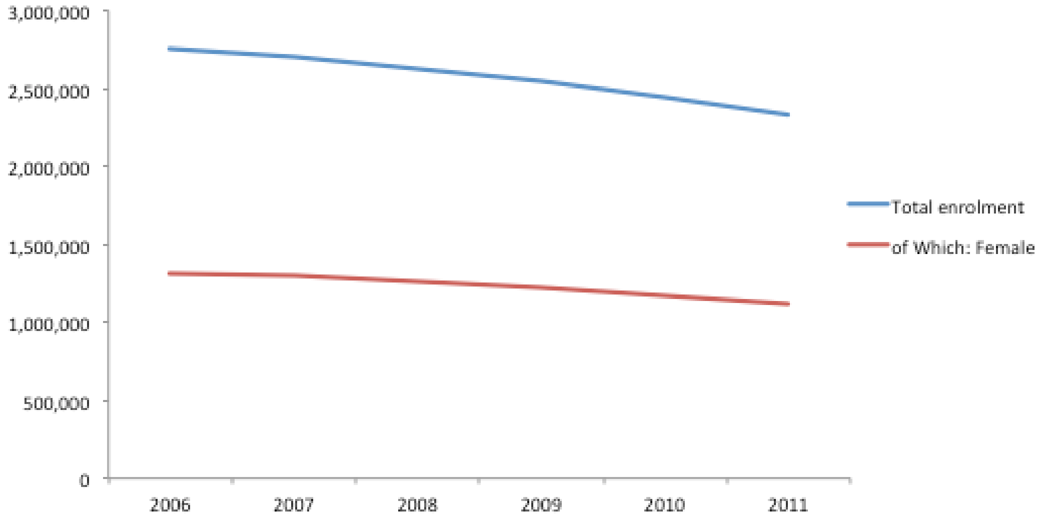
The primary and secondary education STEM landscape

STEM-related course and participation of students

As discussed in the last section, all students are required to study science-related subjects as a compulsory course until grade 11th. Science-related subjects have different arrangements at various levels. In grade 1st-2nd, society, arts & humanity and science & living technology are integrated into one subject called life science. From grade 3rd to grade 9th, science is taught as a separate subject with the name of Science & Living Technology. This is the most obvious difference from the situation in Mainland China where science is taught as three separated subjects—physics, chemistry and biology in the junior high school rather than an integrated discipline area. From grade 10th to 11th, science is divided into four subjects - physics, chemistry, biology and earth science. And at the end of grade 11th, students need to choose their track from two options: natural science and social science, in order to prepare for the college entrance exam. It could be seen that in Taiwan, science subjects in senior secondary education include earth science, which is not usually involved in science teaching. Another difference relies on the requirement of mathematics, in China, math is a compulsory subject throughout the 12-year schooling; while in Taiwan, math, as other science subjects, is only required as compulsory until grade 11th. In grade 12th, it becomes optional.

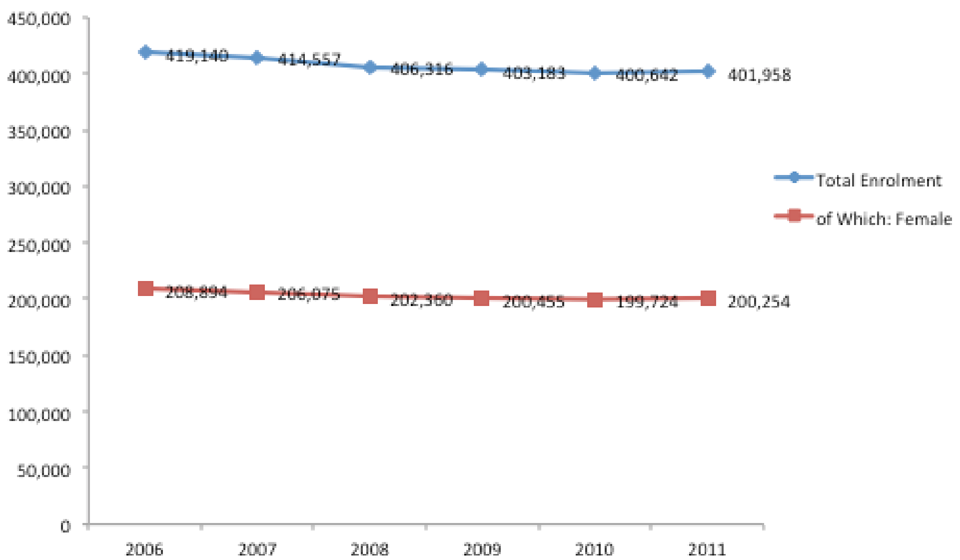
The number of students participating in science learning in primary and junior secondary schools (which is called 'citizen education' in Taiwan) is the total number of all primary and junior secondary students. Fig.8 shows the changes of the number of students in primary and junior high schools from 2006 to 2011. The data show an obvious decline in the number of students because of the decreasing birth rate in Taiwan. The proportion of female students maintained at around 48 percent during the six years.

Fig.8 Number of Students in Primary and Junior Secondary School by Gender (2006~2011)



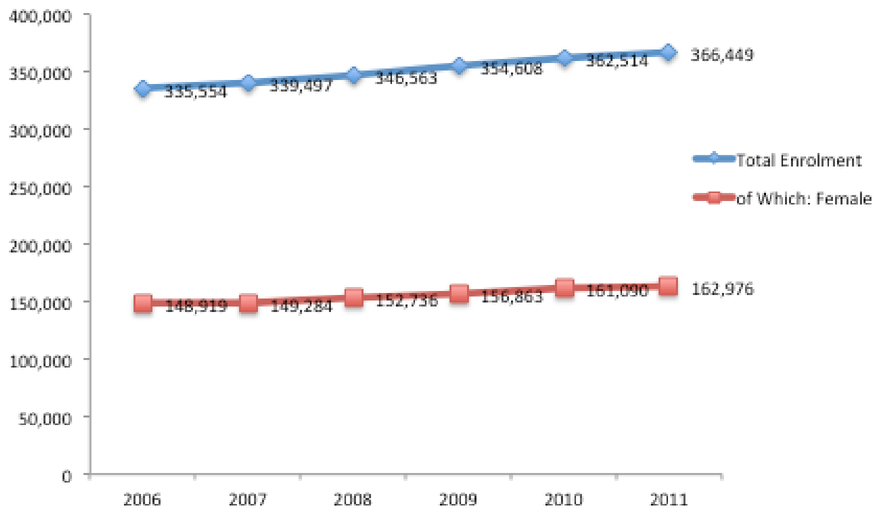
Unlike most of the western countries that use a kind of decentralized curriculum in senior secondary school, the Taiwan authorities have developed standardized curriculum and students cannot choose which subjects they would like to learn in senior high school. The number of students in senior secondary school provides a rough picture of science participation at senior secondary level, but it should be bared in mind that in grade 12th, only students choose Natural Science track are required to take science and math courses (see Fig.9). There was also a drop of the number of students at senior secondary level; however, the decrease has slowed down in the last three years. And at senior secondary level, more female students are involved; the proportion of male and female is nearly equal. And from 2006 to 2011, the percentage of graduates of senior secondary school entering HE grew by 4.11 percent, reaching 95.24 percent.

Fig.9 Number of Students in Senior Secondary School by Gender (2006~2011)



In Taiwan, a large proportion of junior high school graduates enter technical/vocational schools instead of traditional senior high schools for study. Since these vocational schools mainly offer subjects related to technology, the vocational students are also a potential source of STEM manpower. Especially in recent years, more vocational students continue their study in HEIs after graduation, enlarging the sci-tech talents pool. The figure below shows the changes in the number of vocational students between 2006 and 2011. In contrast to the trend of senior secondary school, the number of vocational students increased gradually in the six years. It means vocational schools, as an alternative choice of traditional academic senior schools, have become more popular among students. The ratio of senior secondary students to vocational students decreased by 0.15 between 2006 and 2011. In terms of gender difference, less female students choose vocational schools for their study, taking up approximately 44 percent of overall enrolment. Big progress has been made to encourage vocational students to pursue HE after their graduation. In 2006, 69.79 percent of vocational graduates continued their study in HEIs. In 2010, the proportion reached 79.64 percent, increasing by almost 10 percent. It resulted in more STEM capable talents.

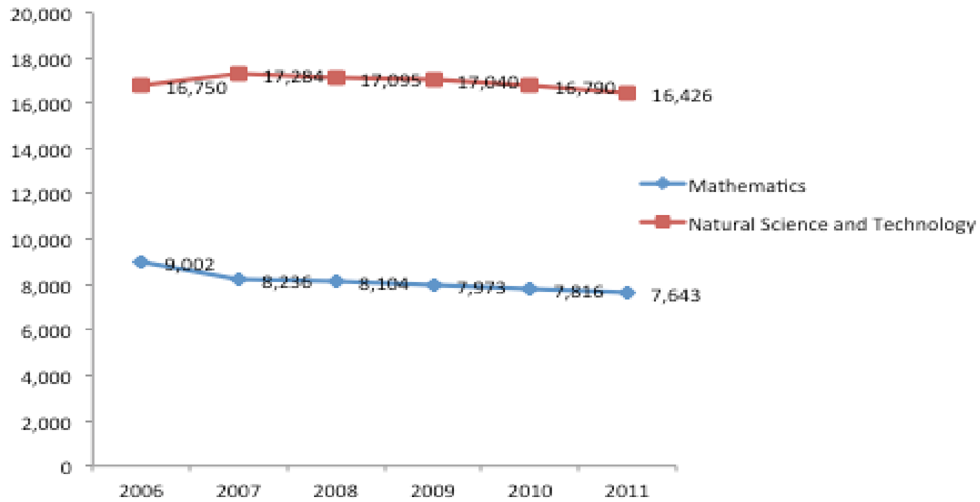
Fig.10 Number of Students in Vocational School by Gender (2006~2011)



Teachers of STEM at primary and secondary levels

Science teachers play a decisive role in the success of science education since they influence the students directly and dominate the classroom and learning process to a large degree. Fig.11 presents the changes in the number of science and mathematics teachers in primary and junior secondary schools. From the data it could be seen that the number of mathematics teachers declined in the six years, which might be because of the drop in student numbers, while the number of Natural Science and Technology teachers peaked in 2007 and then decreased gradually in the following years. The proportion of female math teachers in primary school decreased by 14.56 percent in the six years from 68.58 percent in 2006 to 52.04 percent in 2011. The counterpart in junior high school did not change much, remaining at 41 percent. The proportion of female teachers of natural science and technology maintained around 48 and 45 percent at primary and junior secondary levels respectively in the 6-year period. There are no specific statistics of separate science subjects' teachers in senior secondary schools. From the available data, it should be noted that the overall quality of teachers in senior secondary schools improved in the last six years. The proportion of Master degree holders grew from 33.71 percent in 2006 to 46.56 percent in 2011. Similar trends can be captured at primary and junior secondary levels as well. The proportion of Master degree and above holders increased by 21.36 and 14.48 percent in primary and junior secondary schools respectively.

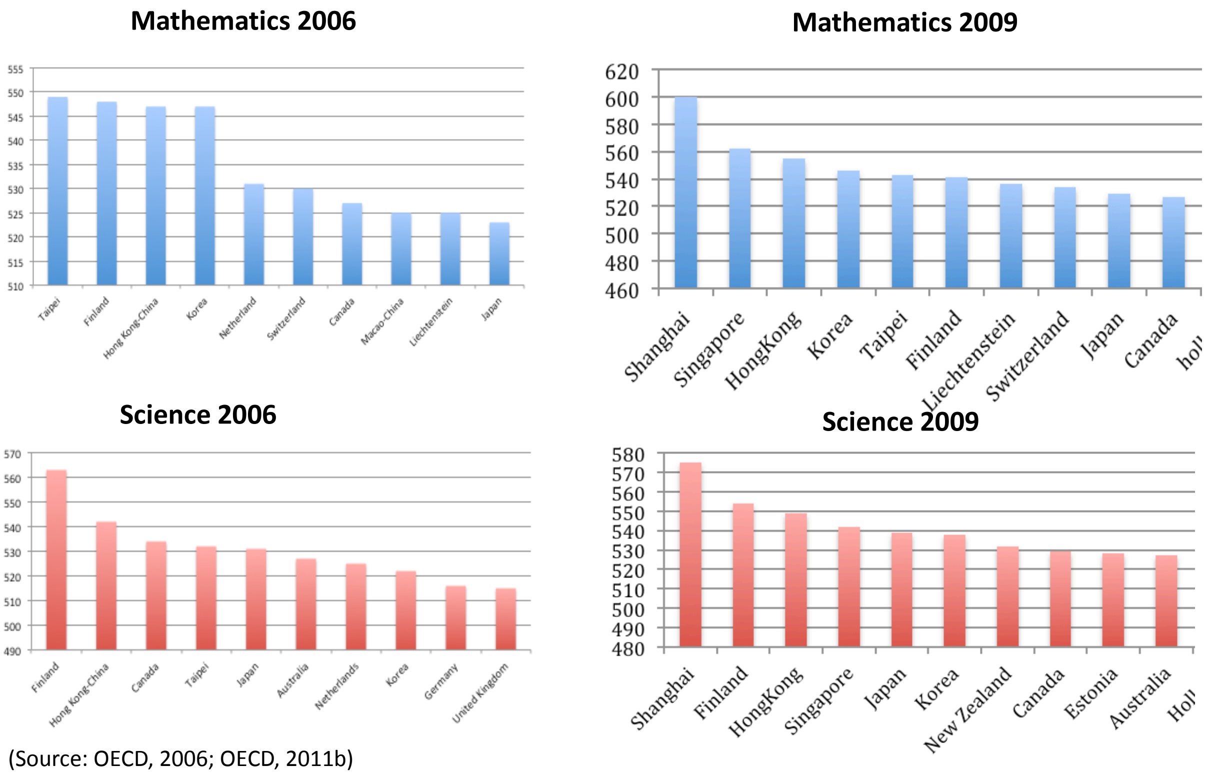
Fig.11 Number of Teachers in Math and Natural Science and Technology in Primary and Junior Secondary School (2006~2011)



International comparison of students' achievement in STEM-related subjects

Maintaining and growing a STEM-capable workforce starts with a strong primary and secondary mathematics and science foundation: one that encourages not only basic skills and application abilities but also stimulates student interest toward future STEM careers. Focused and structured curriculum during the primary and early secondary school years build fundamental mathematics and science skills that translate into higher performance of Taiwanese students on international assessments and competitions. In PISA 2006, Taiwan (Taipei) ranked first in students' math performance and ranked 4th in science. In PISA 2009, there was a slight decline in both math and science performance, dropping to 4th and 12th separately (see Fig.12).

Fig.12 Average Results of Student Performance in Mathematics and Science in PISA 2006 and 2009 by countries



(Source: OECD, 2006; OECD, 2011b)

According to the results of 8th grade students' performance in mathematics and science on TIMSS (Mullis, Martin, Foy, & Arora, 2008, 2012), which is also an international assessment of students testing knowledge of math and science, Taiwan's performance in math dropped from No.1 in 2007 to No.3 in 2011 and the performance in science maintained a high level, ranking 2nd in both 2007 and 2011 (Table 3).

Table 3 Taiwan 8th Grade Student Performance on TIMSS: 2007and 2011

Strategies for improving the quality of STEM teaching and learning

In order to fulfill the goals of science education at primary and secondary levels, the Taiwan authorities have launched a series of education reforms over the last two decades, focusing on three main aspects: science curriculum, assessment and teachers' cultivation and professional development, aimed at improving the student's science-related knowledge and abilities.

Reforms of science curriculum

	Mathematics	**Science**
2007	1st (598)	2nd (561)
2011	3rd (609)	2nd (564)

In 1998, the MoE in Taiwan issued the *National Education 9-Year Curriculum Outline* and it was set into action from 2001. Before the new curriculum was launched, science was taught as a separate subject. The new curriculum emphasized the integration of science teaching and school-based curriculum development, combining all science subjects into one discipline area called Natural Science and Living Technology. It also outlined the specific requirements for students' ability development in science, such as active research and exploration, independent thinking and problem-solving abilities and the use of sci-tech and information (J.-M. Wang & Zhang, 2011; Xiong & Chen, 2006). In terms of textbooks, the development of textbooks is now organized by the school itself rather than centralized textbook edit. Schools are required to establish curriculum research groups, developing their own textbooks that match their contexts (Y.-Z. Zhang & Wei, 2003). In addition, teachers now are given larger autonomy in delivering lessons. For example, in the science textbooks, the content is organized in different modules. Teachers could choose various modules in their class and they can adjust the content according to the students' needs and capacities (Huang, 2000; Su, 2006).

At senior secondary level, in 2004, Taiwan authorities issued the *Senior Secondary School Curriculum Outline*, which signaled the beginning of education reform in senior secondary schools. From the new curriculum (Table 4), it could be noted that mathematics and four science subjects (physic, chemistry, biology and earth science) are required as compulsory learning in grade 10^{th} and 11^{th}, and the division of natural science and social science only happens in the last year of senior secondary study (MoE, 2008a). The delay of division strengthens students' knowledge of basic science and math, improving the science literacy of overall students. Besides, not only in the traditional senior secondary schools but also in vocational and comprehensive senior schools, science and mathematics are required as compulsory subjects. It provides solid foundation of science knowledge in all types of students and intensifies the links between the three types of upper secondary education (Feng, 2004).

The general trend of new curriculum reform at both primary and secondary levels can be summarised as the following six points:

1. the aim of science education has been transformed from training specialists in science, engineering and technology into fostering all citizens' science literacy;
2. the philosophy of science education has been transformed from elite education to 'science for all';
3. the dominant role of curriculum development is played by schools and teachers rather than government departments;
4. the design of teaching activities transformed from teacher-centered to student-centered;
5. the philosophy of science teaching transformed from science concepts to the combination of science, technology and society;
6. the nature of science lessons transformed from knowledge-oriented to ability-oriented (Z.-W. Chen, 2009; MoE & NSC, 2003).

Table 4 Senior Secondary School Curriculum Outline: Subject and Credit

<table>
<tr><th></th><th colspan="2"></th><th>1st term of Grade10th</th><th>2nd term of Grade10th</th><th>1st term of Grade11th</th><th>2nd term of Grade11th</th><th>1st term of Grade12th</th><th>2nd term of Grade12th</th></tr>
<tr><td rowspan="20">Compulsory Subjects</td><td colspan="2">Comprehensive activities</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td rowspan="2">Literature</td><td>Chinese</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>English</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td rowspan="3">Social Science</td><td>History</td><td>2</td><td>2</td><td>2</td><td>2</td><td></td><td></td></tr>
<tr><td>Geography</td><td>2</td><td>2</td><td>2</td><td>2</td><td></td><td></td></tr>
<tr><td>Citizen and Society</td><td>2</td><td>2</td><td>2</td><td>2</td><td></td><td></td></tr>
<tr><td colspan="2">Mathematics</td><td>4</td><td>4</td><td>4</td><td>4</td><td></td><td></td></tr>
<tr><td rowspan="4">Natural Science</td><td>Physics</td><td rowspan="4">4</td><td rowspan="4">4</td><td rowspan="4">4</td><td rowspan="4">4</td><td></td><td></td></tr>
<tr><td>Chemistry</td><td></td><td></td></tr>
<tr><td>Biology</td><td></td><td></td></tr>
<tr><td>Earth Science</td><td></td><td></td></tr>
<tr><td rowspan="3">Arts</td><td>Music</td><td rowspan="3">2</td><td rowspan="3">2</td><td rowspan="3">2</td><td rowspan="3">2</td><td rowspan="3">2</td><td rowspan="3">(2)</td></tr>
<tr><td>Painting</td></tr>
<tr><td>Life Arts</td></tr>
<tr><td rowspan="3">Living</td><td>Housework</td><td rowspan="4">2</td><td rowspan="4">2</td><td rowspan="4">2</td><td rowspan="4">2</td><td rowspan="4">(2)</td><td rowspan="4">2</td></tr>
<tr><td>Living Technology</td></tr>
<tr><td>Information</td></tr>
<tr><td rowspan="2">Health and P.E.</td><td>Health and Nursing</td></tr>
<tr><td>P.E.</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td><td>2</td></tr>
<tr><td colspan="2">National Defense</td><td>1</td><td>1</td><td></td><td></td><td></td><td></td></tr>
</table>

	Credit/Class per week	29/31	29/31	28/30	28/30	12/14	12/14
Optional Subjects	**12 subjects**	0~3	0~3	0~3	0~3	14~21	14~21
	Credit	0~3	0~3	0~3	0~3	14~21	14~21
	Total Credit/Class per week	33/35	33/35	33/35	33/35	33/35	33/35

(Source: MoE, 2008b, pp. 1-2)

Assessment of science learning

The development of assessment approaches is influenced by the aim of education. It, in turn, has great impacts on the teaching and learning process of science subjects. Before 1993, the assessment in Taiwan was mainly in the form of centralized uniform exams, and the focus of the test concentrated on knowledge, which relies on students' memorizing. Scoring high in the exam did not necessarily mean the student could use the knowledge he learns from textbooks in the daily life. From 1993 to 2001, the major aim of education at that time was cultivating students' problem-solving capacity; consequently, performance assessment was used for the primary school graduation test. However, after the students entered into junior secondary schools, they still needed to face the pressure to be enroled by senior secondary schools based on their performance in knowledge-oriented graduation exam. This situation was regarded as an obstacle to a coherent 9-year compulsory education. Against this context, the *National Education 9-Year Curriculum Outline* was issued (Z.-W. Chen, 2009; MoE & NSC, 2003; Xiong & Chen, 2006).

In accordance with the new curriculum, the assessment approach has also been transformed into teacher dominant assessment. The centralized uniform graduation exam was abolished. At the primary level, multiple intelligence and pluralistic assessments are adopted to evaluate students' learning of science. At junior secondary level, the Basic Competence Test is implemented as the evaluation of students' performance. The focus of the Basic Competence Test is highly related to daily life. Students are not required to memorize or recite the content of textbooks, but use their knowledge or experience to infer the answers to the items (Z.-W. Chen, 2009; Xiong & Chen, 2006). This kind of assessment is compatible with the aim of science education and the curriculum design.

Science teachers' training and professional development

The quality of science teachers largely determines the quality of science education. Therefore, the cultivation of high-quality science teachers is a significant part of science education development. In order to meet the requirements of the fast development of sci-tech, science teachers need to have the capacity to use scientific literature, to understand the aim, curriculum, teaching, learning and assessment of science education, to teach the nature of science, to grasp scientific spirits, to facilitate the development of students' creativity and scientific knowledge and attitude and to foster the students' interest in science (MoE & NSC, 2003). The improvement of the quality of science teachers could be realized through teachers' professional development, which includes pre-service and in-service training. In 1994, the Taiwan authorities issued the *Teacher Education law*, aimed at reforming the traditional teacher cultivation system. Since the launch of the *Teacher Education law,* teachers' education in Taiwan has experienced great changes, transforming from uniform to diverse education system, from planned to reserved education and from government-funded to self-funded education. Not only are the normal universities/colleges eligible for educating students who major in teaching, comprehensive universities also launch programs in teaching, providing more opportunities for students to obtain the qualification of teachers (Xiong & Chen, 2006; Y.-Z. Zhang & Xie, 2006).

According to the *Teacher Education law* (2004), pre-service training for science teachers consists of general learning, subject-related learning and internship. Taking the Guobei Normal University's Science Teacher Program for example, the program is operated in the Department of Natural Science Education. After students are enroled in the program, they are required to learn biology, physics, earth science and chemistry as compulsory subjects and choose one subject as a major subject according to their own preference (Xiong & Chen, 2006). After teachers have been employed in the school, they are still required to taking at least 18 hours or 1 credit training per term or accumulated 90 hours or 5 credits in five years. The in-service training is encouraged to be organized by individual school or regional teacher center (MoE & NSC, 2003).

Vulnerabilities in the current primary and secondary STEM system

Although reforms have taken place in science education in primary and secondary schools in Taiwan for better cultivating students' scientific abilities and boosting students' learning of scientific knowledge, the problems in the current STEM system still draw attention from governmental departments, scholars and educational practitioners. The integration of separated science subjects in the *National Education 9-Year Curriculum Outlines* causes the concern of confusion about subject logic and sequence. Some scholars point out that since the integrated curriculum reduces the requirement for individual subjects' knowledge and results in the setback of student performance in international comparison of science ability (Yang, 2010). In addition, influenced by Chinese culture and Confucian heritage, Taiwan also has the tradition of valuing thinking rather than practicing. Science education is still highly focused on the teaching of knowledge instead of experiment and design. Moreover, at senior secondary level, because of the pressure of college entrance examination, science education is still exam-oriented, resulting in fragmental knowledge learning and ignoring the inference process and the learning of underlying laws. Students pay more attention to the exam scores and have no time to experience reasoning or critical thinking. Teachers also have to adopt standardized teaching methods, providing students the uniform answers rather than encouraging them to think independently (Jin, 2007; Yang, 2010).

The well-established teaching and learning mode cannot be changed in a short term. Since the vulnerabilities have been acknowledged by practitioners, scholars and policy-makers, it could be expected that in the future, with the deepening of educational reform, the existing problems in the current primary and secondary STEM system could be solved step by step. With the advantages of emphasis on education, high responsibility of teachers and students' diligence (Jin, 2007; Z.-Y. Li & Bian, 2001), more STEM capable graduates from secondary schools will pursue HE in STEM fields.

STEM in higher education

In this era of knowledge-driven economy, cutting-edge research and development that produces innovative results have become crucial factors in determining a nation's international competitiveness. The quality of research and development in universities is undoubtedly the key advancing the standing of a nation within the international community (MoE, 2009). In the first National Science Education Conference in 2002, the visions for science education at HE level was proposed as

> cultivating sci-tech manpower who has the abilities to explore and master the operation, transformation and law of development of the nature (MoE & NSC, 2003, p. 9).

In order to obtain the required abilities related to STEM, students need to think independently, to learn actively, to explore new learning areas and methods and eventually, they can conduct frontier and internationally competitive science research by themselves (ibid). Since HE plays an increasingly important role in Taiwan's science and innovative system, this section will take a detailed look at Taiwan's STEM system at HE level.

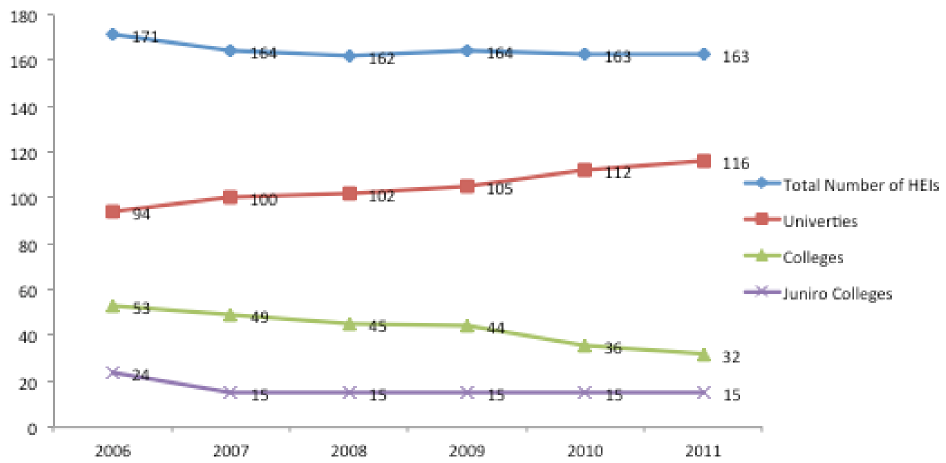
Higher education STEM landscape

STEM courses and student participation at HE level

Institutions

Until 2011, a total number of 163 HEIs in Taiwan provided various levels of programs. Among them, 116 were universities, of which 46 were public. The other 47 were colleges and junior colleges. The figure below shows the changes of the number of HEIs in the last six years. From the data it could be noted that the total number decreased from 171 to 164 from 2006 to 2007 and then maintained. The decrease is caused by the decline in the number of colleges and junior colleges. In contrast, the number of universities expanded from 94 in 2006 to 116 in 2011. The focus of this sector will be the universities and colleges which can grant Bachelor and above degrees.

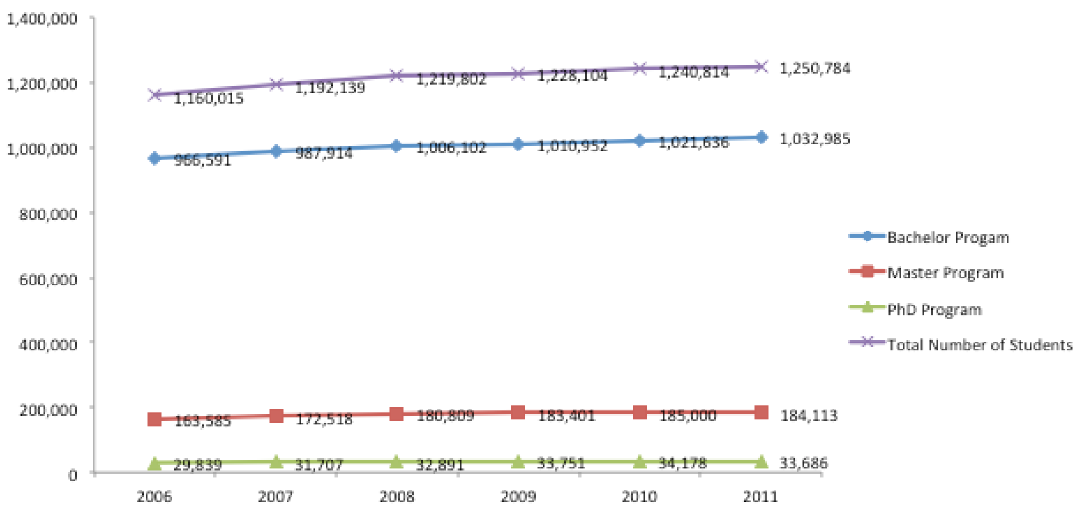
Fig.13 Number of HEIs by type in Taiwan (2006~2011)



Students

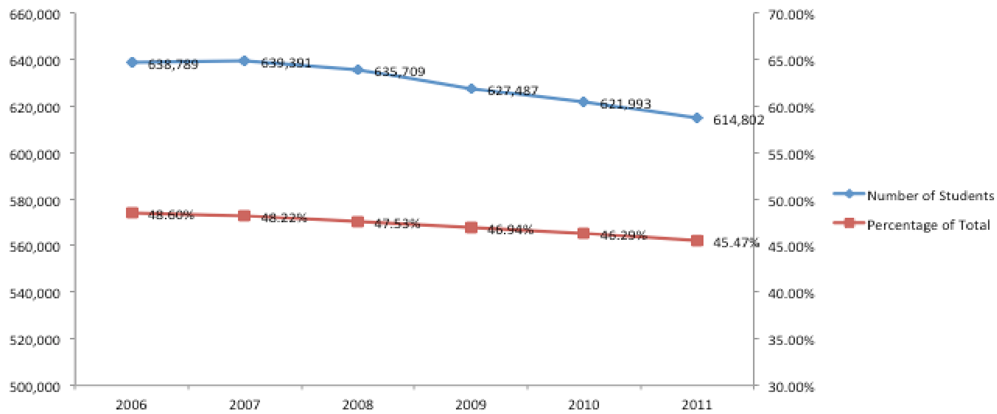
Because of the expansion of Taiwan's universities total enrolment in universities increased by 7.8 percent between 2006 and 2011. Student enrolments in Bachelor programs kept pace with total enrolment, growing gradually in the same period. The number of students participating in both Master and PhD programs grew in the first five years but suffered a slight decline in 2011 (see Fig.14).

Fig.14 Enrolment in Universities and Colleges in Taiwan by Program (2006~2011)



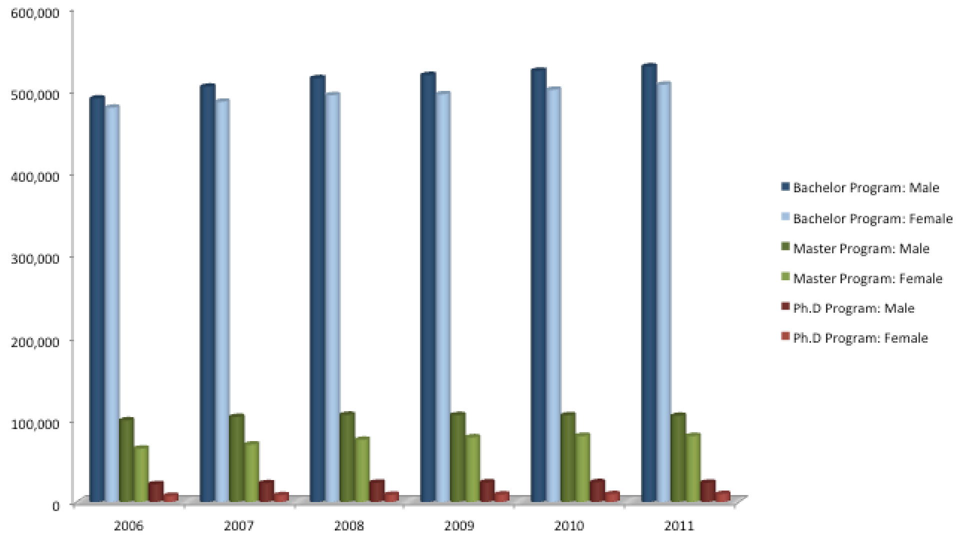
Different trends can be observed in the enrolment of students in STEM-related majors in universities and colleges. The number of students chosing STEM as their majors decreased from 638,789 at all levels of study in 2006 to 614,802 in 2011, by 3.8 percent. The proportion of students that participated in STEM fields dropped from 48.6 percent to 45.5 percent, by 3.1 percent (see Fig.15). In general, among the three categories of study field: Social Science, Humanities and Sci-tech, Sci-tech was still overwhelmingly preferred by university and college students. The decline in the participation in STEM fields means sci-tech majors had already been less popular among university and college students. Since Taiwan's economic prosperity highly relies on the advancement of sci-tech, even the slight decline in the students' participation in STEM fields study should be paid enough attention to find out the underlying reasons for the decrease and then take measures to improve students' participation. Otherwise, faced with the low birth rate and aging society problems, in the future, Taiwan will encounter a shortage of sci-tech manpower and impede the sustainable development of national economy.

Fig.15 Enrolment in STEM Fields at All Levels of Study (2006~2011)



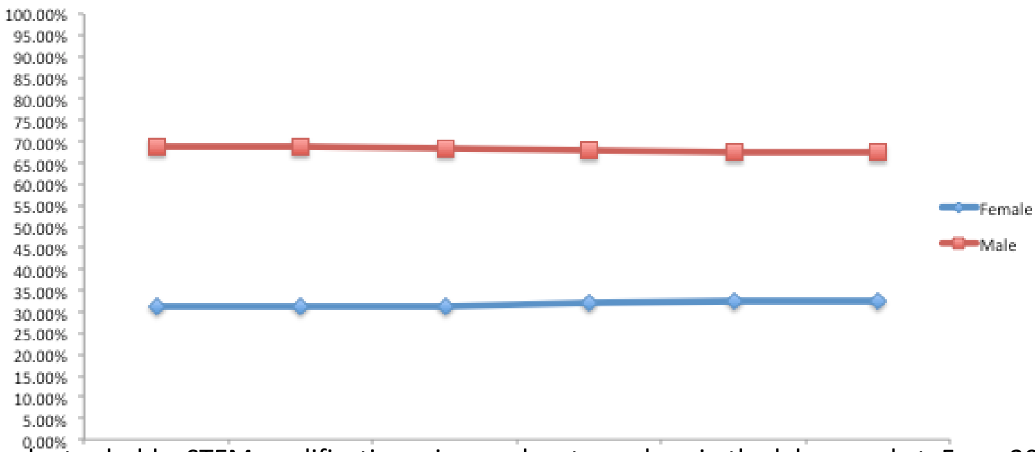
In terms of gender differences in enrolment in different programs (see Fig.16), at Bachelor level the enrolment of male and female students was more balanced; the ratio of male to female students has been maintained at 1.02 to 1.05 during the past six years. At Master level study; male students were almost 1.5 times of female ones. The ratio of male to female students decreased from 1.5 in 2006 to 1.3 in 2011, which illustrates a more even trend in the enrolment of different gender students. The biggest gender difference could be observed at Ph.D program enrolment; male student enrolments were more than double of female students. Like the trend of Master program enrolment, the gap between male and female had been narrowed in the last six years. The ratio of male PhD students to female PhD students dropped by 0.39, from 2.75 in 2006 to 2.37 in 2011.

Fig.17 Student Enrolment at Bachelor, Master and Ph. D levels by Gender (2006~2011)



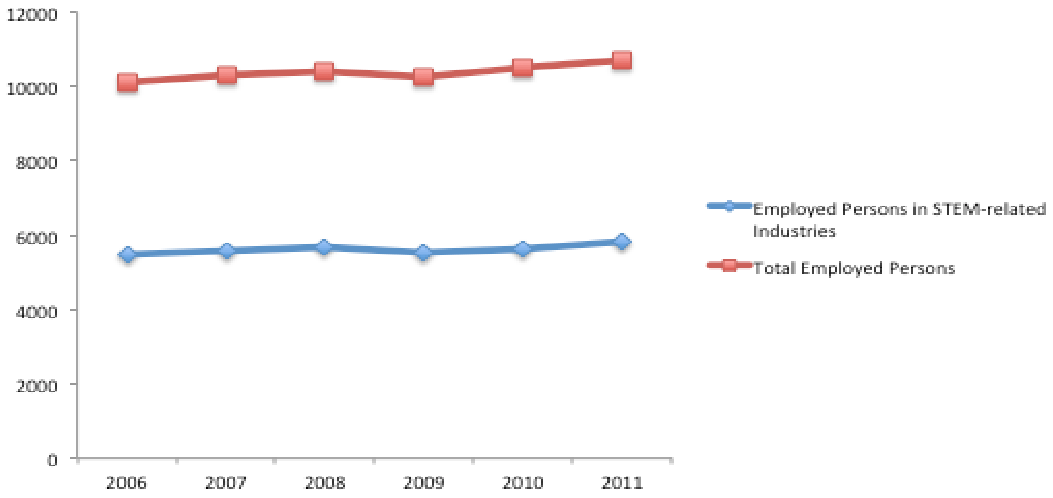
Specific to the gender breakdowns of participation in STEM fields, it could be seen that male students were still the majority of enrolment in STEM majors, taking up more than 65 percent of the places. In the last six years, only a slight increase took place in the participation of female students in sci-tech fields, growing by 1.38 percent (Fig.17). The female participation in sci-tech field is still underdeveloped compared with the male one. Measures should be taken in order to increase the participation of female students and narrow the gap between genders.

Fig.17 Students' Participation in STEM Field at All Levels of Study by Gender (2006~2011)



Graduates hold a STEM qualification win an advantage place in the labor market. From 2006 to 2011, the employees in STEM-related industries took up more than half of the total employment (see Fig.18). In addition, among the top ten high monthly earning industries in 2011, STEM-related fields took 8 places. The average earnings of employees in STEM-related industries reached NT$56,700 per month in 2011, NT$8309 more than the overall average monthly earning (DGBAS, 2012).

Fig.18 Employed Persons by Industry (2006~2011)



(Source: DGBAS, 2012)

STEM academics in HEIs

A close examination of the number of teachers serving in universities and colleges reveals one of the problems faced by the Taiwan HE system - the shortage of academics. The faculty team in HEIs did not expand with the pace of the increasing students' enrolment. In contrast, the number of teachers decreased in 2011 compared with that in 2006. During the six years, the number fluctuated and since 2008 it has kept declining. Among all the teachers, the female ones accounted for approximately 33 percent of the total (see Fig.19). But the quality of teachers has been considerably improved. From Fig.18 it could be noted that the number of teacher with Associate Professor and above titles increased between 2006 and 2011; while the number of instructors decreased by 44.9 percent.

Fig.19 Number of Teachers in Universities and Colleges (2006~2011)

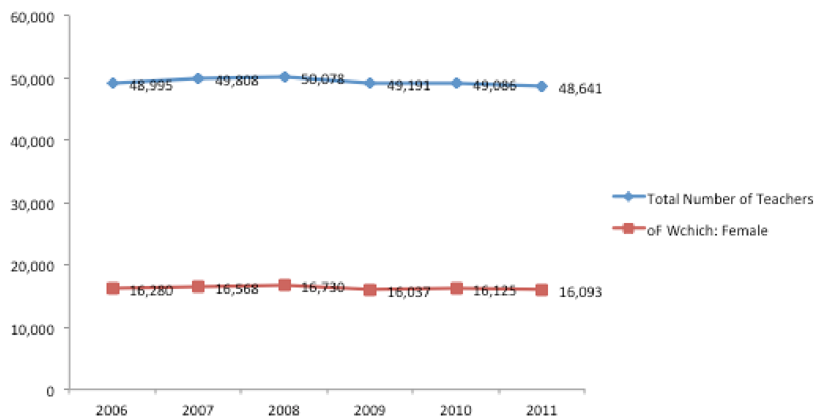
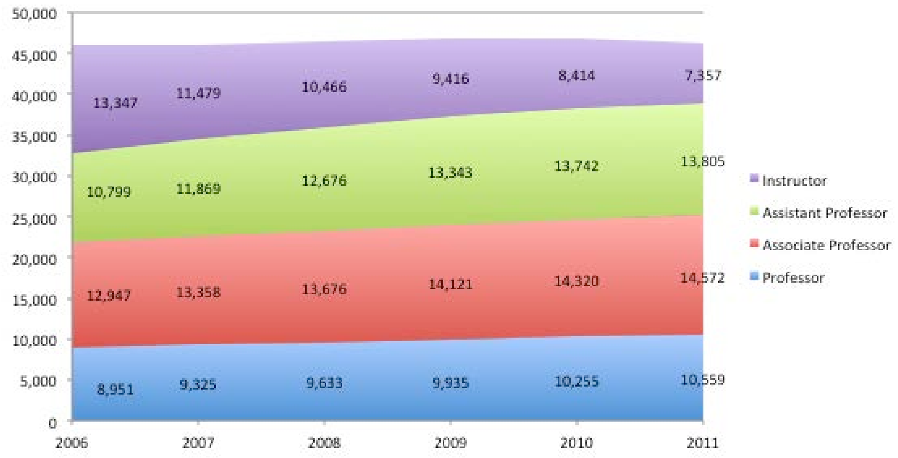


Fig.20 Number of Teachers in Universities and Colleges by Position (2006~2011)

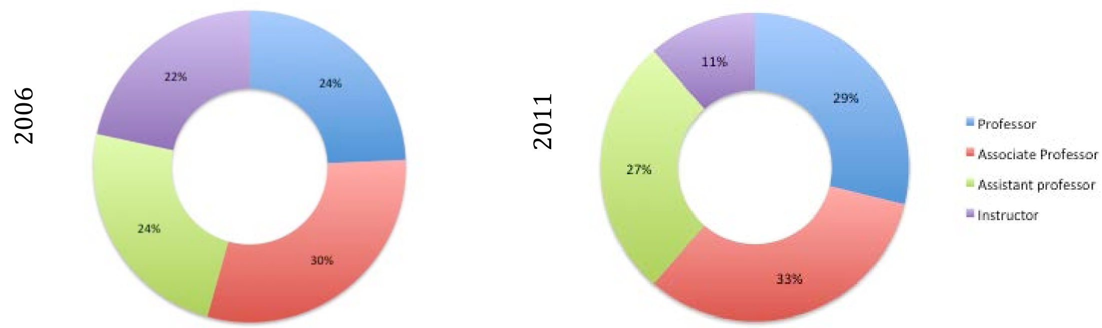


For the academic staff involved in STEM fields teaching, it shows similar trends to the changes of overall academics. The total number of teachers in STEM fields had a small decrease in the six years. And the number of female academic staff was significantly less than the male one. Only around 20 percent of STEM faculties were female. The male ones were almost four times of the female ones. The sci-tech teaching staffs were distributed unevenly in different genders. More females need to be encouraged to take the teaching position in STEM fields (Fig.21).

Fig.21 Number of Teachers in STEM Fields by Gender (2006~2011)

The improvement in the quality of teachers can also be observed in STEM fields. In 2011, the majority of academic staff in STEM majors held the title of Associate Professor and Professor, taking up 61 percent (Fig.22). But for the higher teaching positions (Associate Prof. and Prof.), the female academics in STEM took up only 17.5 percent. It means there was still a lack in high-quality female STEM academics.

Fig.22 Percentage of Teachers in STEM Fields by Position (2006, 2011)



Academic achievement at HE level

The quantity and quality of academic output could be regarded as a sign of research capacity. In terms of papers in SCI, Taiwan ranked 17th in 2011 among all the countries. The total number of papers grew by 48.09 percent between 2006 and 2011. The rank maintained at 16th to 17th (Fig.23). The number of paper indexed by EI increased by 53.07 percent in the same time period, and the rank of Taiwan in EI index increased from 11th in 2006 to 9th in 2011 (Fig.24). In 2011, a total number of 50,305 patents were granted in Taiwan, increasing by 3 percent compared with those in 2006 (see Fig.25). All the data demonstrate that the research capacity of Taiwan kept growing in the last six years, and the HE sector made considerable contributions to the improvement of national overall R&D capacity.

Fig.23 Number of Annual Papers in SCI, Taiwan (2006~2011)

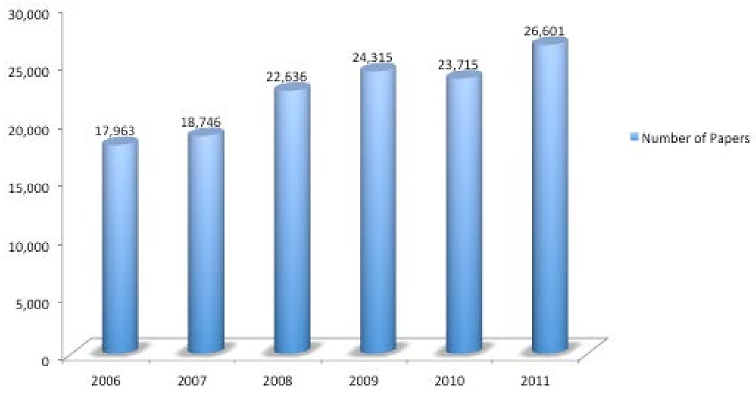


Fig.24 Number of Annual Papers in EI, Taiwan (2006~2011)

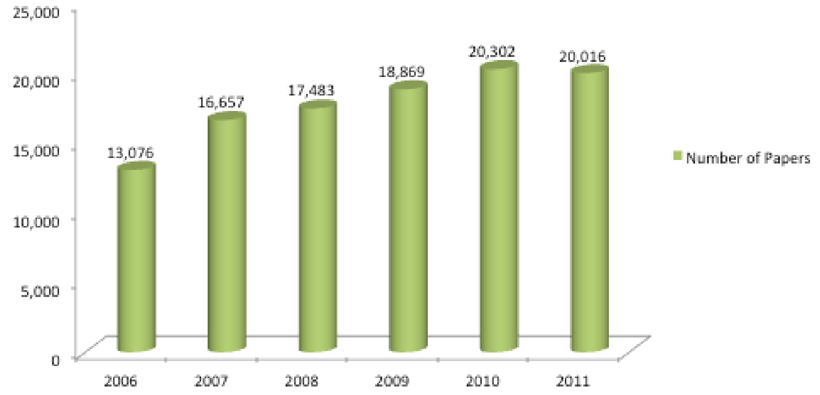
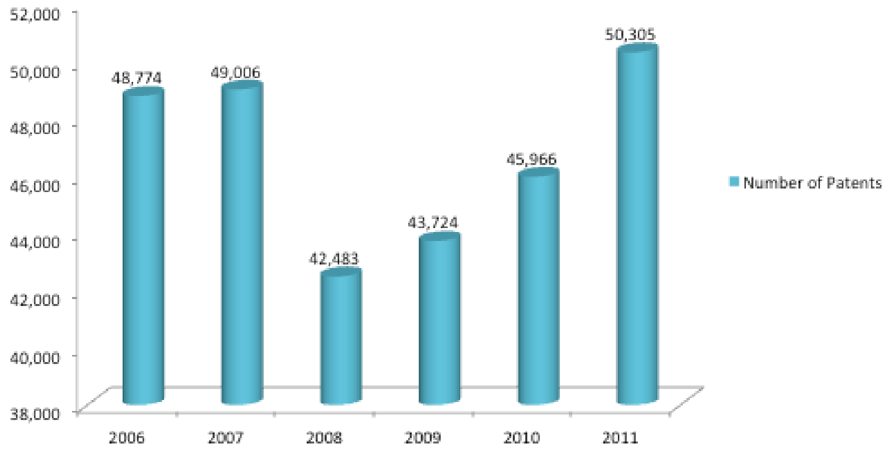


Fig.25 Patents Granted in Taiwan (2006~2011)



(Source: NSC, 2012)

Strategies for facilitating STEM in the HE sector

The rapidly expanding HE system in Taiwan cultivates more sci-tech talents to meet the needs of national industry and economic development. However, it also influences the allocation of educational resources negatively. The ideology of equal distribution throughout all universities results in a dilution in quality across the board. This results in a failure to stimulate universities to establish specific expertise and promote their academic competitiveness. The amount of students enroled in colleges/universities has grown quickly, and resources are unable to keep pace with this expansion. Insufficient resources in turn have caused stagnation among the university teaching and research quality. At the current stage, the development of Taiwan's universities encounters the difficulties of shortage in staff and funding. Since government funding to universities has reduced every year, the student/faculty ratio has become too high to maintain an effective and quality education system (MoE, 2009). All these factors influence the quality of science education at HE level. Taiwan government has already realized the problems, under this context; various strategies at different levels have been initiated to facilitate science education and the overall quality of HE.

World class universities and Research Centers of Excellence

The MoE in Taiwan initiated the *Development Plan for World Class University and Research Centers of Excellence* in 2004 in order to develop first-rate, world-class universities and establish top-notch research centers in distinctive fields through competitive funding and establishing an academic competition environment (MoE, 2009; NSC, 2012). This project encompasses two subprojects:

1. Project to develop first-rate international universities

   The MoE is using competitive funding to assist with the creation of research universities with development potential, boost the efficiency of overall university instruction and research, integrate human resources, improve university management strategies, and establish a sound organizational operation system. This project has invested NT$ 50 billion over five years in twelve universities (the ‘T12’ universities) to boost their international competitiveness. The T12 universities include both large comprehensive universities (e.g. National Taiwan University) and small, specialized universities—both public and private (e.g. National Yang Ming University, a small university specializing in biomedical research).

2. Project to develop top-notch research centers (research fields)

   The MoE is encouraging research universities to establish interscholastic (international) research teams or cooperate with research institutions in specialized areas in order to focus human resources and equipment investments, develop key national research areas, assist with the creation of new opportunities for integration of R&D and innovation, reward the establishment of distinctive areas and new curricula in order to promote key areas of study. The table below shows the universities and key areas receiving subsidies. Among the seven key areas, five of them are science-related (NSC, 2012). It demonstrates that STEM fields are the priorities of the project.

Table 5 Subsidies provided under the Development Plan for World Class Universities and Research Centers of Excellence

Units: NT$100 m

Type	Schools	Phase 1		Phase 2		
		2006	2007	2008	2009	2010
First-rate universities	National Taiwan University	30	30	30	30	30
	National Cheng Kung University	17	17	17	17	17
	National Tsinghua University	10	10	12	12	12
	National Chiao Tung University	8	8	9	9	9
	National Central University	6	6	7	7	7
	National Sun Yat-sen University	6	6	6	6	6
	National Yang Ming University	5	5	5	5	5
	National Chungshing University	4	4	4.5	4.5	4.5
	National Taiwan University of Science and Technology	3	3	2	2	2.2
	National Chengchi University	2.05	3	2	2	2
	Chang Gung University	3	3	2	2	2
	Yuan Ze University	2.32	3			
Key research areas	Chung Yuan Christian University's Film Technology Center	1	0.4	0.7	0.7	0.8
	National Taiwan Ocean University's Fisheries Biotechnology Research Center	1	0.4	0.9	0.9	0.9
	Taipei Medical University's Stroke Research Center	0.6	0.4			
	National Taiwan Normal University's Educational Assessment and Development Center	0.515	0.2			
	National Chung Cheng University's Taiwan Humanities Research Center	0.515	0.1			
	Yuan Ze University's Fuel Cell Research Center			0.9	0.9	0.9
	Kaohsiung Medical University's Environmental Medicine Research Center			0.9	0.9	0.9
Total		100	99.5	99.9	99.9	100.2

(Source: NSC, 2012, p. 69)

In order to guarantee the effectiveness of the project, MoE has developed rigorous evaluation and assessment mechanisms. Academically distinguished and eminent scholars and experts from Taiwan and overseas are invited to form an evaluation committee to review the conditions of campuses and fields of study and judge their performance in the light of both qualitative and quantitative specific annual objectives stated in their plans. A visit and on-site evaluation is conducted annually to gain an understanding of the achievements resulting from each institution’s efforts and the finding thereof made public. A review and evaluation of overall performance is conducted in the third year of subsiding (MoE, 2009; X.-H. Wang, 2008). The forging of world-class universities and enlistment of outstanding talents require a long-term investment plan. In order to continue to develop internationally competitive HEIs and to provide strong incentives for universities to participate in this plan, the government has promised ten years of funding support. NT$500 million has already been earmarked for the first five-year period, while funding for the second five-year period will be set aside by the MoE from its annual budget (MoE, 2009).

Industrial-academic collaboration

In the 1990s, Taiwan moved toward building its innovative capacity and in the 2000s it is drastically upgrading the role of universities and RIs in providing fundamental R&D, in acting as incubators of new, knowledge-based firms, and in building the country's innovative potential through intellectual property (IP) protection and commercialisation activities. Universities and RIs have been the engines that drive Taiwan's technological upgrade, and continue their role through new emphasis on patenting and entrepreneurial technology transfer (Chang & Hsu, 2002; Mathews & Hu, 2007; V. F.-S. Wu, 2000). The government relies on S&T programs to promote joint industrial-academic research. The knowledge innovation fostered by collaboration between industry, universities and RIs in these programs is the key to their success. To better promote joint research involving industry, universities and RIs, in recent years the MoE has developed strategies addressing up-, mid- and downstream scientific and technological development aimed at enhancing Taiwan's innovative capacity (NSC, 2012).

The MoE announced the *Regulations Governing University Industrial-Academic Collaboration* in 2006 to provide basic guidelines for university involvement in industrial-academic collaboration, and has been performing the 'University Industrial-Academic Collaboration Performance Assessment' on an annual basis in 2007. Apart from the MoE's efforts to encourage universities to take industrial-academic collaboration as an important part of their administrative scope, performance assessment results have served as a key quantitative indicator for MoE subsidies to universities implementing relevant projects. The MoE has provided subsidies to 11 HEIs under this program (ibid).

Peters and Fusfeld (1982) have identified several reasons for universities to seek cooperation with industry, including industry provides a new source of money for the university; industrially sponsored research provides students with exposure to real world research problems and provides university researchers a chance to work on intellectually challenging research programs; and some government funds are available for applied research, based upon a joint effort between university and industry. Similarly, Atlan (1990) points out the motivations for industry to increase the cooperation with universities as getting access to manpower, including well-trained graduates and knowledgeable faculty; getting access to basic and applied research results from which new products and processes will evolve; finding solutions to specific problems or professional expertise, not usually found in an individual firm and getting access to university facilities, not available in the company.

Three mechanisms for technology dissemination between industry and universities have been put into practice in Taiwan: Technology Transfer Centers (TTCs); Technology Trade Centers (usually web-based systems); and incubators. HEIs are encouraged to establish TTCs for licensing of technology and know-how generated, in order to increase linkages with industry and to gain more funding support from both industry and the government. In order to enhance business opportunities in the supply and demand for technology trading markets in Taiwan, in 2002 Industrial Technology Research Institution created *Taiwan Technology Marketplace*, which is the largest integrated technology-trading platform in Taiwan. Under this program, the Small and Medium Enterprise Administration of the Ministry of Economic Affairs is funded to encourage the creation of a series of incubators in Taiwan, many of which are linked with, and located within, leading universities (Chang & Hsu, 2002; Mathews & Hu, 2007).

Taking National Taiwan University (NTU) as an example. NTU is Taiwan's premier university, for both teaching and research. In 1996, NTU established a Commission on Research and Development to help faculty members and students commercialize their research results and to create a friendly environment for the development of medium- and small-sized business. The NTU *Innovation and Incubation Center* (NTU IIC) was formally founded in 2001 on a new campus near the main NTU campus. The center aims to assist medium- and small-sized companies in the areas of electronic, informational technology, information management, automation, and biotechnology industries, in accordance with the specialty and research programs of related colleges of the University. The center offers management solution packages, technical and infrastructure consultation, as well as assistance in the steady growth and expansion of knowledge-based medium- and small-sized companies (Mathews & Hu, 2007).

With regard to the MoE's success at facilitating industrial-academic collaboration, technology licensing cases involving subsidized universities and companies and resulting from industrial-academic collaboration were worth roughly NT$453 million in 2009, and this figure represented growth of 43 percent compared with the equivalent figure of NT$317 million in 2008. Furthermore, companies attributed to NT$2.55 billion in revenue to the results of joint industrial-academic research, which was 15 percent higher than the equivalent figure of NT$2.23 billion in 2008. A total of 310 firms occupied incubation centers, and 73 new firms took up occupancy; these figures represented growth of 21 percent and 24 percent respectively compared with those of 2008. HEIs are regarded as contributing not just their own innovation results but more fundamentally to the country's innovative capacity, that is, to its ability to sustain innovation and enhance it as the country's industrial structures becomes more knowledge based.

The prosperity of technical universities in Taiwan

There are two types of universities in Taiwan: comprehensive and technical. Technical universities were upgraded from technical colleges in 1990s. Universities of technology recruit students mainly from vocational high schools, and they are also allowed to enrol graduates from traditional academic high schools. As a result of the upgrade, technical universities have a similar structure to general universities and offer degree programs from Bachelor to PhD. Technical universities are responsible for the sci-tech education and advanced sci-tech education in Taiwan. For sci-tech education, the aim is to train qualified technologist for various industries. The curricula are designed to teach the student science-related knowledge and mathematics theories, and students are required to manipulate sophisticated machines, equipment and apparatus or to manage complex production processes. They can obtain a Bachelor degree after completing the course. For advanced sci-tech education, the aim is to cultivate engineers. In the curricula, in addition to the advanced science and mathematics theories, students are also required to acquire advanced knowledge of a special technical field and management. This kind of program will last two years and grant a Masters degree when the student graduates (Hsiao, 2006; Rui, 2009; Ye, 2009).

Technical universities in Taiwan have developed explicit goals to complement the general university; meanwhile, to meet the demands of social economic development and the students' life-long development. In order to cultivate application-oriented talents, the teaching and learning in technical universities focus on practice rather then theory. In general, students studying at technical universities in Taiwan receive vocational training that differs from the general university curriculum, which emphasize practical knowledge and skills. The curricula are designed to be student-oriented and enterprise-oriented. The teaching plans are jointly developed by teachers, enterprise staffs and graduates. The majors and curricula are adjusted according to the analysis of market demands. The adaption to the society and sustainable development of capacity of students are highly valued in technical universities (Rui, 2009; Ye, 2009). Many technical universities have been adopting sandwich programs containing practical training to help their students acquire professional know-how. Obviously, sandwich programs are a useful part of a practical learning environment and minimize the gap between theory and practice. The implementation of sandwich programs at a university may consist of a half-year or a full year in a company. Basically, learning alternates between school and factory (Hsiao, 2006; Tsia, 2010). Unlike the situation of Mainland China where vocational education is usually peripheral in mainstream HE system, the prosperity of Taiwan's economy is closely related to the development of technical universities.

Like the general university, technical universities in Taiwan also place considerable attention in the cooperation with industry. As a result of the close relationship with enterprises, students are trained in necessary skills for employment and when they graduate, they can easily be employed. Experienced technical staff in different enterprises comprise a large proportion of teaching staff in technical universities. They provide solid warrantee for the training of enterprise-oriented talents since they do not only possess high qualifications but also have extensive practice experiences, and they clearly know the exact demands of enterprises. Moreover, the cooperation with industries enhances the research ability of technical universities. The major funding of technical universities comes from enterprises and universities encourage their teachers to obtain the funds from enterprises by actively involving in the market-oriented research. Some of the laboratories in technical universities have realized self-development (Rui, 2009; Tzeng, Yeh, & Ma, 2005; Ye, 2009).

The cooperation between the Ford Company in Taiwan and the technical university serves as a good illustration. The cooperative relationship began in 1991. Initially, one or two teachers of a technical university provided vehicle maintenance and repair training classes for Ford Company in Taiwan. Being satisfied with the quality of training, Ford gradually increased the number of training classes conducted by the technical university, as well as increased the number of classes related to general technical support services. Furthermore, both side also signed agreements relating to each cooperative project and updated these agreements annually. The cooperative projects include a wide range of programs, such as optional courses taught by experienced Ford technical staff in the technical university, planning a demonstration platform for all car systems in special topic classes and providing visiting opportunities to the Ford factory for the students. The liaison between the technical university and Ford Company creates a win-win situation for both of the parties involved (Tzeng et al., 2005).

In addition, targeting the technical university and college system, starting in 2002 the MoE provided subsidies for the establishment of six 'MoE Regional Industrial-Academic Collaboration Centers' located through northern, central, and southern Taiwan to offer a channel for industrial-academic interchange and matching of potential R&D partners. Beyond the regional industrial-academic collaboration centers, since 2003 the MoE has additionally granted subsidies to technical colleges establishing technology R&D centers, which are an important means of strengthening the ties between industries and technical HEIs, deepening technological R&D results, and accumulating industry-university collaboration experiences (Mathews & Hu, 2007; NSC, 2012).

In order to further promote interchange and research cooperation between technical colleges and industry, MoE accounted the *Implementation Guidelines for the Promotion of Industrial-Academic Collaboration between Technical Colleges and Universities and Industry Parks* in 2005. Moreover, since 2010 the MoE has provided subsidies to 12 technical universities for the establishment of 'joint technology development centers' in specific industry-related areas; these technology development centers will integrate the resources of existing R&D units, lift the technological standards of relevant industries and add value to existing R&D results (NSC, 2012).

Other strategies for improving STEM in HE sector

In addition to the above mentioned three major strategies to improve the sci-tech education in Taiwan's HE system, other measures have also been developed and implemented. As the high-tech industry in Taiwan has matured, it has begun to realize that what is more in demand today are those more roundly and firmly educated engineers with wider disciplines than those who were traditionally educated. In other words, today's industry prefers to employ inter-disciplinarily educated engineers who are more tailored for high-tech environment. Against this context, Taiwan's universities promote interdisciplinary curriculum system to meet industrial needs. Some inter-disciplinary curricula are gaining popularity in engineering schools in Taiwan, such as IC Design and Manufacturing Curriculum, Electronic Packaging Curriculum and Energy and Resources Curriculum. Inter-disciplinary curricula not only cross the traditional departmental boundaries, but also tread the interface between universities and industry. Some of them are more appropriate for schools to offer, and some are ideal for companies to offer, in particular those courses that are closely related to processes or machinery (F.-M. Li, 1999).

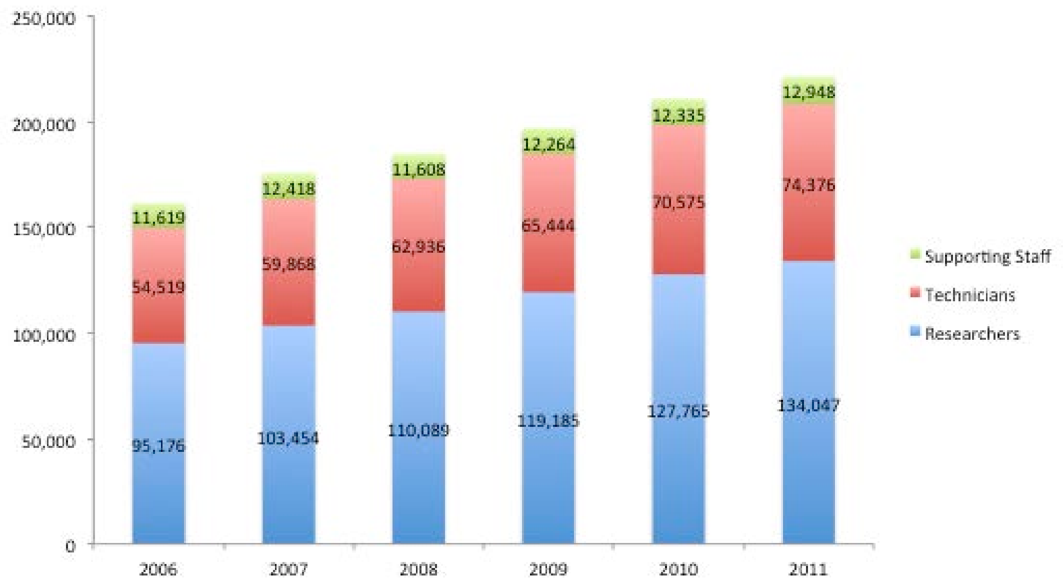
Moreover, the MoE has promoted the *Program for Promoting Academic Excellence of Universities* since the year 2000, and the *Program to Improve Public Universities' Main Graduate Schools* since the year 2002, which have had a truly marked effect on the coalescing of talent. The plans have succeeded in forming inter-disciplinary research groups and improvements in related institutions' basic facilities for PhD courses; a total of NT$5.3 billion in funding over six years was allocated towards the integration or formation of 28 research groups, and the publication - both foreign and domestic - of more than 3500 articles. With much yet to be accomplished in the overall integration of talent, personnel, resources and organizational operation, the *Plan to Promote Integration of Research Universities* was initiated in 2002, with NT$1.7 billion provided in funding over the past five years (MoE, 2009).

STEM personnel and employment

R&D manpower in Taiwan is divided into three categories: research personnel, technical personal and support personnel. All the three categories of personnel grew gradually over the past six years. In particular, the number of research personnel group increased at the fastest rate, and accounted for approximately 60.55 percent of all R&D personnel in 2011. The percentage of support personnel has fallen in the recent years (see Fig.26)[3].

[3] In this section, all the data without specific note are sourced from (NSC, 2012), and the tables and figures in this section are summarized by the author according to the data

Fig.26 R&D Personnel (FTE) by Type (2006~2011)



The relative number of R&D personnel in the general population (R&D personnel intensity) has grown steadily during the most recent six years, and reached 12.5 person-years FTE per 1,000 employments in 2011. According to the latest statistics of the R&D personnel intensity in 2010, Taiwan is only less than Denmark (12.6) and Finland (17.0), but higher than that of Korea (11.1), Sweden (10.9), Japan (10.4), Singapore (10.3) and even much higher than Mainland China (1.6). The figures below show the changes of R&D personnel intensity in Taiwan between 2006 and 2011 and the comparison of different countries' R&D personnel intensity in 2010.

The number of female research personnel rose steadily from 39,868 person-years in 2006 to 55,317 person-years in 2011. However, there has been no significant change in percentage of female research personnel among all research personnel. Females were twice less involved than male ones in research activities (Table 6).

Fig.27 Researcher per 1,000 Employments (FTE) in Taiwan (2006~2011)

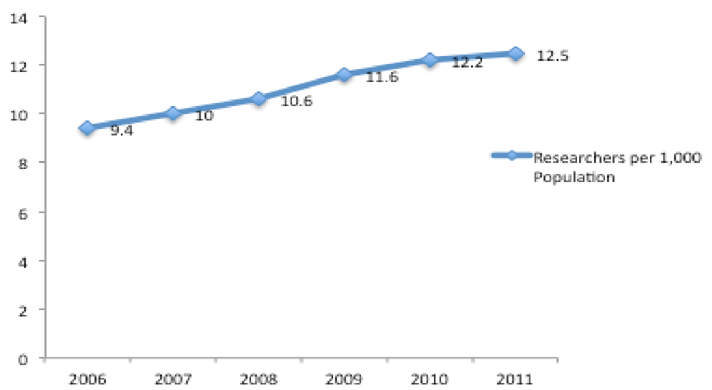


Fig.28 R&D Personal (FTE) by Country (2010)

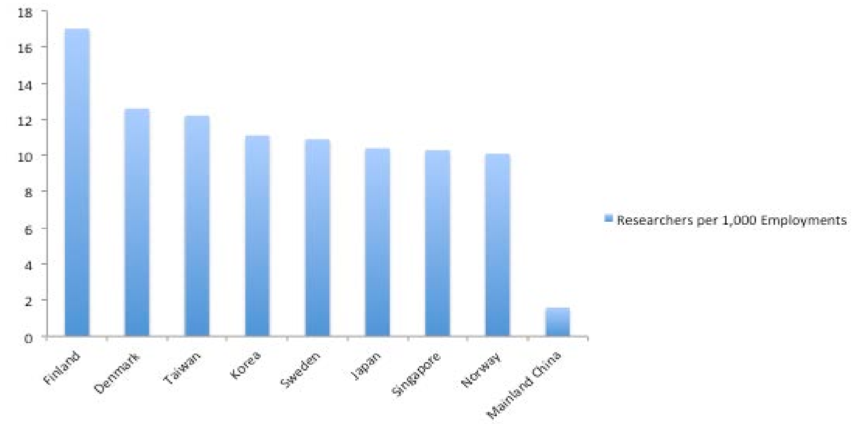


Table 6 Female R&D Personal (FTE) in Taiwan (2006~2011)

	2006	2007	2008	2009	2010	2011
Female R&D Personnel	39,868	42,997	44,633	48,466	51,930	55,317
Percentage of Total	24.71	24.46	24.17	24.62	24.65	24.99

The business sector has the largest proportion of research personnel and the proportion even kept increasing in the last six years, followed by HE sector and government. But the proportion in both of the two sectors declined (see Fig.29). In terms of qualifications, the number of Master degree holders has increased the most (4.9 percent), accounted for more than 40 percent of all R&D personnel in Taiwan. The proportion of PhD-holders and Bachelor-holders also grew by 1 percent and 0.4 percent over the past six years. Researchers who hold Junior College degrees fell down to 10.7 percent in 2011 (Fig.30).

Fig.29 R&D Personal (FTE) by Sector of Employment (2006~2010)

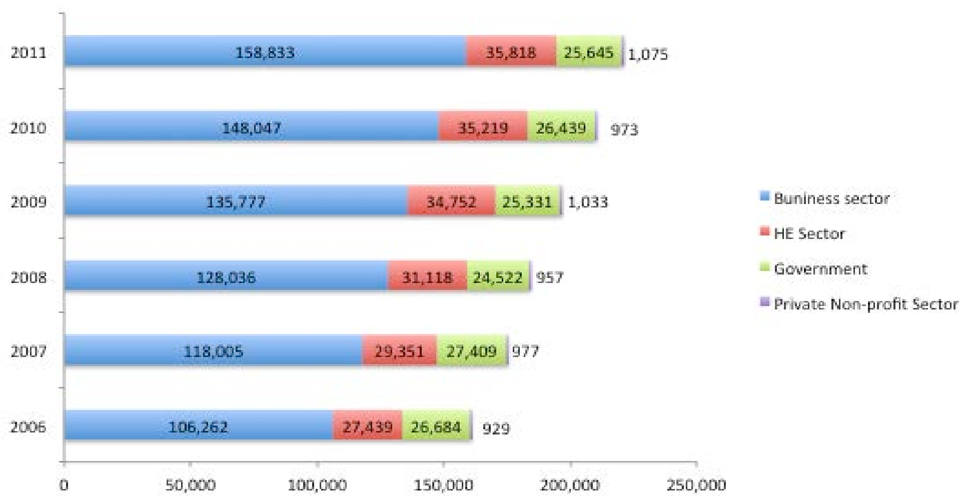
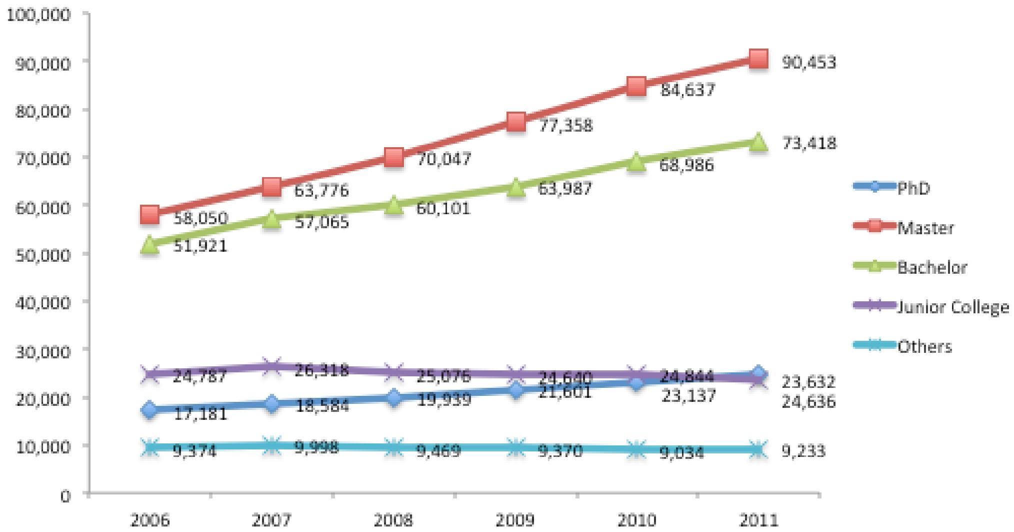


Fig.30 R&D Personal (FTE) by Qualification (2006~2010)



Conclusion

In the last three decades of the 20th century, Taiwan made the transformation from an agricultural economy to a silicon economy. This transformation had given Taiwan one of the highest living standards in Asia, if not the world. In the 21st century, with the rapid rise of regional and global challenges and competition, in order to cope with the changes and keep pace with the development of modern knowledge-economy, Taiwan's government has initiated a series of large reforms at all levels of sci-tech education in recent years since qualified sci-tech manpower plays a decisive role in maintaining the prosperity of the national economy and improving national competitiveness. Like many other Western countries, although Taiwan's authorities have taken various measures to improve the sci-tech education at all levels, Taiwan faces the same problems like the decrease of student numbers in primary and secondary levels and the decline of student's participation in science-related majors in HE.

In order to provide better science education to students and improve the overall scientific literacy of citizens, Taiwan's MoE launched several reforms at primary and secondary levels. New curricula, assessment approaches and teachers' professional development plans have been implemented. The basic science education transformed from the cultivation of scientists to 'science for all'. But in terms of students' performance in internationally comparable tests (e.g. TIMSS and PISA), no significant improvement could be observed about students' scientific abilities. At the HE level, the Taiwan government initiated the *World Class Universities and Research Centers of Excellence* plan for strengthening the research capacity of elite Taiwan universities, aiming at forging internationally competitive universities in Taiwan and enhancing the role of HEIs in the overall national innovation system. The cooperation between industry and academics has been strengthened to reap benefits to both of the two parties. Another major measure to enlarge the sci-tech talents pool in Taiwan is to upgrade technical colleges into technical universities to offer more practical and application-oriented courses to students. With both of the traditional academic and vocational education, a comprehensive science education system has emerged in Taiwan. Since the development of high-tech industry in Taiwan is highly reliant on the quality of sci-tech manpower, in the future, the science education system in Taiwan will continually draw attention from the central government and related departments. It could be foreseen that educational reforms will last and more strategies will be developed to further promote science education in Taiwan and benefit the national economy ultimately.

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