International Journal of Business, Human and Social Sciences
ISSN: 2517-9411
Vol:7, No:12, 2013

An Exploration on Competency-Based Curricula in Integrated Circuit Design

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Abstract**—**In this paper the relationships between professional competences and school curriculain IC design industry are explored. The semi-structured questionnaire survey and focus group interview is the research method. Study participants are graduates of microelectronics engineering professional departments who are currently employed in the IC industry. The IC industries are defined as the electronic component manufacturing industry and optical-electronic component manufacturing industry in the semiconductor industry and optical-electronic material devices, respectively. Study participants selected from IC design industry include IC engineering and electronic & semiconductor engineering. The human training with IC design professional competence in microelectronics engineering professional departments is explored in this research. IC professional competences of human resources in the IC design industry include general intelligence and professional intelligence.

Keywords**—**IC design, curricula, competence, task, duty.

I. Introduction

FIRSTLY, the demand for human capital by the integrated circuit (so called IC) industry is explored in this paper. In the classification of the electronic industry by the Industrial Bureau, Ministry of Economic Affairs, the electronic industry is a "key industry" in Taiwan. The IC design industry is a division of the electronic industry. The classification of human resources in the IC design industry includes the research and development category, and manufacture category [1]. Through the arrangement of human resource data in supply and demand in the electronic industry from 2006, the total demand of human resources in the electronic industry is as high as 44.3% of total human resource demand of Taiwan, which is more than the percent of other industries [2]. The demand for human resources constitutes a great amount in the electronic industry in Taiwan. Therefore, it is worthy to explore and analyze the training model for human resources in the IC design industry. The human resources of the IC design industry include IC design and IC test fields in accordance with the classification of the electronic industry [3]. The IC design and IC test human resource data of Table I reveal the increase inhuman resource demand year by year, which indicates the critical phenomenon of IC design human resources [3].

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TABLE I
THE DEMAND OF HUMAN RESOURCE IN IC DESIGN INDUSTRY FROM 2010 TO 2012(SOURCE: ARRANGEMENT IN THIS STUDY) (UNIT: PEOPLE)[3]

Electronic industry	2010	2011	2012
IC design	27,220	30,281	31,606
IC manufacture	74,076	80,310	82,420
IC packaging	39,420	45,614	46,403
IC test	14,728	17,166	17,464
In Total	155,444	173,371	177,893

In this paper, the research background and motivation are based on the demand for large amounts of human resources in the IC design industry. The training performance of IC design professional human resource at a department of microelectronics engineering in a university is explored. In addition, the relationship between the school curriculum and necessary duties and tasks of the IC design industry are also investigated to promote the production capacity and performance of the IC design industry. The demand rate for human resources is more than the supply rate of that in the IC design industry. However, both unemployment and job vacancies appear simultaneously in the IC design industry. To investigate this problem as mentioned above, this paper explores the relationship between school curricula and necessary duties and tasks in the IC design specialized field. Because the IC design industry possesses the properties of being both high cost and highly knowledge intensive, the training of human resources of the IC design specialized field is quite complex. The plan and realization of school curricula are important both in accordance with professional curriculum needs and necessary duties and tasks for learning in school and in industry respectively. Professional competence of human resources acts as an intermediary between the professional curricula in school and necessary duties and tasks in industry. Professional competences include both general intelligence and professional intelligence. The school curriculum includes a general curriculum and professional curriculum. There are two research themes in this paper. One is the relationship between school curriculum and professional competence in human resources. The other is the relationship between necessary duties and tasks in industry and professional competences in the human resources.

School based curriculum is defined not only as including general curriculum and professional curriculum but also including theoretical curriculum and practice curriculum. Infrastructure of school-based curriculum is based on teacher, student, teaching material, and internal and external environments [4]. Therefore, the school-based curriculum should be planned and approved by the school-based

curriculum committee. This is the reason why some institutions are not able to make the correct plan, decision, and judgment in special curricula [5]. The electronic industry is defined as including the semiconductor companies, semiconductor component companies, and information, optical-electronic and communication companies, in upstream industries, midstream industries, and downstream industries, respectively. According to the classification of professional job assignment, the semiconductor industry includes the semiconductor design industry, semiconductor fabrication industry, semiconductor packaging industry, and semiconductor testing industry. Semiconductor component industry is classified as the semiconductor device manufacture industry, passive component manufacture industry, printing circuit board manufacture industry, and other electronic components and systems manufacture industry. In this paper, the researched industry is the semiconductor design industry [1], [6]. Professional competence is an ideal type. A profession includes two significant characteristics. One is that the profession must be subjected to professional competence in a specialized field. The other is that a profession must include the ethics of professional service [7]. Competence is one kind of the personal characteristics which can be implemented and complete their duties and tasks. Characteristics of competence include possessing the requisite function and quality. Competence is natural such as competitiveness, which is a congenital aptitude and can be obtained through the training process [8]. Therefore, competence can be classified according to general intelligence and professional intelligence.

II. Research Method and Design

In this research, the research scheme is the relationship between professional competence and school curricula. The research framework is shown in Fig. 1. The research variables include independent variables, dependent variables, and intermediary variables. Independent variables, dependent variables, and intermediary variables are school curriculum, and necessary post, and professional competence, respectively. School curricula include the general curriculum and professional curriculum. Professional competences include general intelligence and professional intelligence. Necessary post includes the duties and tasks. The research method of semi-structured focus group interview is used in this research. According to the above mentioned descriptions of the research motivations, research objects, and research variables, the research hypotheses are as follows:

Hypothesis 1: Necessary duty is influenced by necessary task in IC design industry.

Hypothesis 2: Necessary task is influenced by professional competence in IC design industry.

Hypothesis 3: Professional competence is influenced by school curriculum in IC design industry.

Fig. 1 Research framework in IC design industry for school curriculum, professional capability, and necessary duties and tasks in IC design industry

The research sample purely includes graduates who completed the school based curriculum from a microelectronics engineering professional curriculum and are currently working in the IC design industry. Because of the relative paucity of such graduates, the method of research sampling is purposive sampling. Therefore, the research method adopts focus group interview methods to interview the graduates who have completed the microelectronics engineering professional curriculum and are currently working in the IC design industry.

III. Research Result and Discussion

In this research, electronic industry is defined as including the semiconductor industry and other optical-electronic component material and device manufacture industry in electronic component manufacture industry and in optical-electronic material and device, respectively. A company engaging in semiconductor manufacture and design is defined as being in the semiconductor industry. The classification of the semiconductor industry contains IC manufacture industry, IC packaging and test industry, IC design industry, and discrete device manufacture industry. A company engaging in optical-electronic material and device manufacture, and optical equipment manufacture is defined in the other optical-electronic component material and device manufacture industry. Based on the great variety of electronic industries, professional titles in the IC design industry are categorized into IC design engineering and electronic semiconductor engineering for investigating professional intelligence and general intelligence. The electronic industry (so called semiconductor industry) is classified into electronic component manufacture industry and optical-electronic material and device industry. The electronic component manufacture industry can be defined in the industries of semiconductor and electronic component manufacture industry, but not including optical-electronic material and device manufacture industry. Therefore, the electronic component manufacture industry includes semiconductor industry, passive electronic device manufacture industry, print circuit board manufacture industry, and other electronic component manufacture industry. In the electronic component manufacture industry, the semiconductor industry is defined into the semiconductor manufacture and design industry which includes IC fabrication industry, IC packaging and test industry, IC design industry, and discrete device manufacture industry. The optical-electronic material and device industry is defined as the industries engaged in optical-electronic material and device, and optical equipment manufacture, such as the

manufacturers of liquid crystal panel, plasma panel, light emitting diode, solar cell battery, digital camera, and optical lens. In this paper, the electronic industry is just including the semiconductor industry of electronic component manufacture industry and other optical-electronic component manufacture industry of optical-electronic material and device industry. According to the classification of the electronic industry, professional titles include IC design engineering and electronic semiconductor engineering, as presented in Table II.

TABLE II
TYPICAL PROFESSIONAL TITLES OF IC DESIGN INDUSTRY (SOURCE: THIS STUDY)

Typical professional titles	Categorized professional titles
Analog design engineering Digital design engineering Lay out engineering System engineering Mix signal engineering Memory design engineering Customer design engineering Design integrated engineering Digital signal engineering Logical design engineering Verify engineering Monolithic microwave IC engineering	IC design engineering
Computer hardware engineering Applied engineering a Device engineering	Electronic semiconductor engineering

IC design engineering contains analog design engineering, digital design engineering, lay out engineering, system engineering, mix signal engineering, memory design engineering, customer design engineering, design integrated engineering, digital signal engineering, logical design engineering, verify engineering, and monolithic microwave IC engineering etc. Electronic semiconductor engineering integrates computer hardware engineering, applied engineering and device engineering etc. The human resources as abovementioned are all trained through the microelectronics engineering based curricula.

In this research, the research participants in a survey from purposive sampling have completed a professional based curriculum in IC design profession and are currently working in the IC design industry. The classification of research participants to realize the focus group interview research follows from their common completion of a school based curriculum in the IC design profession. The graduates after completing the IC design curriculum contain IC design engineering specialists in the IC design industry and electronic semiconductor engineering specialists in the semiconductor industry. Because the management of electronics companies is generally diversified and integrated, characteristics of each electronic company are different and professions at each electronic company involve high discrepancies. Therefore, the classification of research participants is follows their school based curriculum, but not by following industry type. Table III indicates the research participants for the focus group interview of the IC design profession. The participants are all graduated from a 2-year senior college program, all were of the male sex, and all had completed a bachelor degree or above in the microelectronics engineering field.

TABLE III
RESEARCH PARTICIPANTS OF FOCUS GROUP INTERVIEWS IN THE IC DESIGN PROFESSION (SOURCE: THIS STUDY)

Participants	B1	B2	B3	B4
Gender	Male	Male	Male	Male
Academic structure	2-year senior College program	2-year senior College program	2-year senior College program	2-year senior College program
Graduated year	2004	2004	2004	2004
Highest qualification degree	Bachelor degree	Bachelor degree	Bachelor degree	Master's degree
Occupation	Present employment	Present employment	Present employment	Present employment
Employed location	Science-based Industrial Park	Science-based Industrial Park	Science-based Industrial Park	Science-based Industrial Park
Employed industry	IC design industry	IC design industry	IC design industry	IC design industry
Profession title	IC design engineering	IC design engineering	IC design engineering	Electronic semi-conductor engineering

Also, the research participants are all employed in the defined IC design industry or electronic semiconductor industry of the electronic industry. All participants are employed in a Science-based Industrial Park to act as IC design engineering and electronic semiconductor engineering whose tasks are closely related with the IC design profession. The IC design profession is also one of the school-based curriculum fields.

According to the research results of semi-structured focus group interviews, the IC design course and IC fabrication course are the core courses of school-based curriculum in IC design possession, as shown in Table IV. The IC layout course is a related course. The courses as above are listed in the core professional curricula in the IC design profession. After learning the core professional courses, the graduates will be qualified in the duties and tasks of the IC design industry such as IC design engineering and semiconductor engineering. However, the plan of the school-based curriculum in the IC design profession is not in accordance with the research results as above. Therefore, the graduates working in the IC design industry suggests that the IC design course, IC fabrication course, and IC layout course must be enhanced in the IC design-based curriculum.

TABLE IV
RESEARCH RESULTS OF FOCUS GROUP INTERVIEWS IN THE IC DESIGN PROFESSION (SOURCE: THIS STUDY)

Participants	B1	B2	B3	B4
Degree of job satisfaction?	High	Medium	High	High
Degree of putting professional competence you have learned to good use?	High	Medium	High	High
Degree of learning performance in profession?	High	High	Medium	High
Degree of putting general competence you have learned to good use?	Medium	Medium	Low	Medium
What are the most useful professional subjects?	IC lay out IC Design	IC design IC fabrication	IC fabrication	IC fabrication

By way of the focus group interview, current job satisfaction of most IC design participants is significantly high, which reveals that learning performance of IC design relative curricula is in accordance with current work performance demands for IC design tasks. Because the occupations of the participants are stable in their job as IC design professionals, the reliability and validity of the research results as above are significant. For the high job satisfaction of IC design participants, the participants will continuously input great effort into the IC design industry and IC design tasks. The phenomenon represents a good internal organization behavior. Therefore, high job satisfaction of IC design participants will reduce their leaving rates and increase their work performance. The employee's behavior and work performance can be evaluated by evaluation of job satisfaction [9]. Professional curricula from the learning of school-based curricula can be efficiently transformed into professional intelligence and then applied in necessary duties and tasks of IC design positions. Therefore the IC design teachers must carefully consider the "How to learn to…?" for learners, but not just the "How to teach…?" for teachers. The best teaching method for the IC design profession is the guided teaching process, in which the learner must have many opportunities to participate, discuss, and present their ideals and then raise the level of learning through self-fulfillment. The professional competence IC design teachers must have faith, values, role identification, and contingency abilities current with the state of the art and the teaching of professional knowledge and techniques [10]. Therefore, the IC design teachers must also possess the general competences of self-reflection and solving problems to complement the teaching of the IC design profession [11]. In addition, after the IC design participants complete the school-based curriculum of the IC design professions, all participants should reach high executing levels of performance of necessary duties and tasks in the IC design industry. This phenomenon is essential so that IC design participants possess high skill competence, information, and motivation to implement the necessary task for creating much more contributions and advantages in their IC design company [12]-[16]. Taking a broad view as above, it is known that the IC design courses of school-based curriculum could make the learner not only obtain professional intelligence in the IC design field, but also to implement the necessary tasks of the IC design industry.

In this interview, it appears that the IC design participants could not transform the general curricula into general intelligences and then also apply the general intelligences to the necessary duties and tasks of the IC design industry. This phenomenon is more significant than that of the IC fabrication industry. This may be because the IC design industry is a knowledge intensive and know-how intensive industry, but the IC fabrication industry is a technology intensive and labor intensive industry. Employees of a know-how industry must possess high adaptability in interpersonal relations, communications, negotiation and attitudes. Therefore, IC design participants suggest that the learning of general intelligences from the school-based curriculum is not enough to handle the necessary preparation for a career. The reason for this may be that general intelligence is categorized into procedural knowledge and conditional knowledge of cognitive learning theory, but not declarative knowledge [17]. Both procedural knowledge and conditional knowledge are defined by the applications of knowledge in the specific fields by using wisdom, which is also a characteristic of general intelligence. While the procedural knowledge and conditional knowledge is transformed into the external behavior of humans, the transformation is influenced by the external environment, which is different in the statement knowledge of professional intelligence. The teaching and learning activities of general intelligence must proceed through gradual progress and move in circles, which includes awakening stage, amplifying stage, teaching stage, and transferring stage by following the multiple intelligences learning theory. The teaching and learning activities must be learner-centered, but not teacher-centered. The teaching and learning activities must be corrected following the characteristics of different learners [18]-[20]. The IC design participants could not apply general intelligence in necessary duties and tasks. The cause may be that the IC design participants do not learn the whole general intelligence, which may necessitate improving the plan and realization of the general curriculum by following the stages of multiple intelligences learning theory. The IC design industry is widely possessed of creativity and specific characteristics. Therefore, training of human resources in the IC design profession requires enhancing the teaching and learning activities in general intelligence even more so than for other industries.

IV. CONCLUSIONS

After the general intelligence and professional intelligence are learned, the human resources can be employed in the IC design industry. Then the human resources can complete the duties and tasks of IC design for enhancing production capacity and performance of the IC design industry. IC design participants all expressed high satisfaction for their current tasks in the IC design industry via semi-structured

questionnaire survey and focused group interviews survey. After the professional curricula are learned, the professional intelligences can be applied in the duties and tasks of the IC design industry. Both duty and task performance requirements are high, after the school-based curricula of the microelectronics engineering professional department are learned. However, currently the general intelligences are not able to be obtained from the general courses of the microelectronics engineering curriculum, and the general intelligences are also not able to be applied in their current industry duties and tasks. The phenomenon as abovementioned is more significant in the semiconductor fabrication industry. Besides, the major core professional courses in IC design for the IC design industry are the IC design course and IC fabrication course. The IC layout course is a minor core professional course. In addition, core courses of the IC design curriculum should include IC design course, IC fabrication course, and IC layout course to serve as foundations for IC design engineering and semiconductor engineering professions. By way of the focus group interview, the IC design participants presented high working satisfaction. The professional intelligences are also able to be transformed and applied in the necessary duties and tasks of the IC design fields, which reveals their high performance of professional intelligence. However, the general intelligence needed cannot be learned by way of the general curriculum and applied in the necessary duties and tasks of the IC design industry, which will be explored in future study.

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