Development and Implementation of a Practice-Oriented Masters Program in Engineering

Leyla CONRAD
Georgia Institute of Technology, Packaging Research Center, 813 Ferst Drive, Atlanta, GA 30332-0560, USA, leyla.conrad@ece.gatech.edu, www.prc.gatech.edu

Bethany BODO
Radford University, Office of Academic Assessment, Box 6976, Martin Hall 341, Radford, VA 24142, bbodo@radford.edu

Rao TUMMALA
Georgia Institute of Technology, Packaging Research Center, 813 Ferst Drive, Atlanta, GA 30332-0560, USA, rao.tummala@ece.gatech.edu, www.prc.gatech.edu

Gary MAY
Georgia Institute of Technology, School of ECE, 777 Atlantic Drive, Atlanta, GA 30332-0250, USA, gary.may@ece.gatech.edu, www.ece.gatech.edu

Joseph HOEY
Georgia Institute of Technology, Office of Assessment, 225 North Avenue, Atlanta, GA 30332-0325, USA, joseph.hoey@oars.gatech.edu

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ABSTRACT: *Microsystems and Information Technology is the largest industry in the world, approximately $1.2 Trillion currently, and is expected to grow to $3.0 Trillion within a decade. To sustain this growth not only new products need to be brought to the global market place but also new human resources to develop them. Very few programs exist today in the U.S. and around the world to produce any significant number of electronic packaging engineers. Individuals who arrive at careers in electronic packaging do so with a single discipline background in science or engineering and are trained by industry on the job. The dynamic and global nature of the industry, however, requires an entirely different approach. As a result of this need, the microsystems Packaging Research Center (PRC) faculty together with the Center's industry members, have developed the first entrepreneurial and practice-oriented certificate program in microelectronics systems packaging. This new practice-oriented Master's program is a response to the industry need for a strong professional Master's program. It is primarily designed for students who plan to go immediately into industry after obtaining a masters degree rather than seek a Ph.D. The program has three major components: (1) an engineering component, (2) a management and business component, and (3) an internship component. The engineering component focuses on system-level understanding and hands-on laboratory experience, coupled with fundamental scientific knowledge in key packaging-related disciplines. The management component focuses on management of technology (particularly aimed at achieving national roadmap goals), entrepreneurship, and global aspects of the packaging enterprise. The internship consists of either a domestic or international industry experience. Students who complete all three components successfully receive a microelectronic packaging certificate.*

This paper describes the details of the program and discusses its implementation in three engineering schools at Georgia Tech.

1 MOTIVATION AND INTRODUCTION

Microelectronics and Information Technology (IT) is a trillion-dollar industry. It has been acting as the driving engine for science, technology, engineering, advanced manufacturing and the overall economy of the U.S. and other participating countries. Of this trillion-dollar worldwide market, hardware still

accounts for more than $700 billion. Of this $700 billion, microsystems packaging (MSP), defined as both devices and their packaging at the IC and system level, accounts for about $250 billion. Of this, the packaging, without devices, accounts for about $110 billion. The Packaging, defined as the bridge between ICs and end-product systems, accounting for 10% of the entire IT market is a very important strategic technology for the electronics industry. Its strategic technology importance comes about because it controls the size, performance, cost and reliability of all end product systems. It is, therefore, the limiting factor and a major barrier to all next-generation electronic systems.

Over the next decade, the growth of this industry must come from new microelectronics and packaging technologies and the necessary human resources to take this technology to market place. These and other factors present major educational barriers in providing both the quality and quantity of engineers necessary to support the growth of the packaging industry. Unlike most other fields, packaging is the ultimate cross-disciplinary technology involving electrical, mechanical, computer, materials, chemical engineering as well as physics and chemistry. The multi disciplinary nature of this field in return did not lend itself to any educational program of significance at higher education institutions. In the absence of the academic community fulfilling this need, industry performed this educational mission by recruiting engineers mostly from single disciplines and training them at company site.

The electronic packaging engineering profession is directly tied to the manufacturing sector. Roughly 90% of employed packaging engineers work for the packaging industry. Hence industry should be the driving force for electronic packaging engineering education. The recent years fierce competition, both global and in USA, require companies to look for engineers who can do many things. Industry has recognized the need for a different type of engineer not only one of technical excellence but one who can also accomplish business alliances and identify emerging markets [11]. The pressure introduced by the rapidly changing advancements in electronic packaging technology and the development of the next generation of products will require more globally competitive engineers than the current educational system can provide. In order to produce well trained, highly competitive engineers, who will apply emerging technologies to the global market, universities should now focus on providing a more comprehensive, system-level and global education. This type of education should contain science, technology, manufacturing, business economics, teamwork, management, global markets, as well as foreign culture and languages.

In response to this need, the Packaging Research Center in partnership with the U.S. electronics industry, has embarked on one of the most comprehensive, system-level and global electronic packaging education programs in the world [16, 17]. At present, the Center involves about 31 faculty, 140 Ph.D. students, 75 MS students and 75 undergraduates from four departments. The PRC's education goals target students at all levels. Its mission is not only to train undergraduate and graduate students, but industry engineers and pre-college students as well. The Center has developed extensive graduate and undergraduate courses over the past ten years. Altogether, more than 30 courses with significant electronic packaging content have been created, each incorporating leading edge research findings. Among these courses, three are system-level and several are lab-based. With the availability of these courses, a new curriculum with an electronic packaging focus has been developed for both graduate and undergraduate students. In addition to the packaging curriculum, a new Practice-Oriented Masters program has been developed that offers for the first time a global education program involving business, management and foreign culture, as well as a microelectronic packaging certificate, as discussed in the following sections.

In the last two decades manufacturing and engineering fields have undergone dramatic changes in the design and manufacturing process, the management process and the increased use of technologies. As a result of these, the product development cycles have been shortened and the frequency of introduction of new technologies has increased. In spite of these technological advancements and the continuing evolution of engineering practices engineering education has not changed appreciably in the past 50 years. Only in recent years a call for action have been published by several engineering education studies to reform engineering education [19, 7, 18. 4, 21]. It is now evident that engineers must supplement their technical mastery with business, team work and communication skills, and an understanding of ethical and global issues [12, 9]. In order to satisfy industry's needs many engineering educators emphasized the need for a practice-oriented curriculum and implementations have been suggested at all levels of graduate

school [6, 1, 5, 2, 10]. Very recently, several institutions added an "entrepreneurial" component to their engineering programs to provide their students an understanding of essential business practices and prepare them better for industry jobs [20, 14, 13, 15].

2 APPROACH

The PRC's POM program is a response to electronic packaging industry's need for a strong professional Master's degree program for students planning to go immediately into industry rather than seeking a Ph.D. degree. Therefore, the target population for the program is recent BS recipients in science and engineering as well as junior engineers in the packaging industry. The goal of the program is to provide students with the following knowledge and skills.

- Deep packaging knowledge,
- Interdisciplinary and cross-functional skills,
- Hands-on work experience,
- Economics and management education,
- Industry experience,
- Exposure to international concepts.

The program has three major components (see Table 1): (1) an engineering component, (2) a management component, and (3) an internship component. In 12 to 15 months students gain an MS degree in engineering with a certificate in microelectronic packaging, complete the requirements for a minor in management and intern with a potential future employer. The certificate in electronic packaging designates the technical focus while degrees are granted by the participating units such as Electrical and Computer Engineering, Mechanical Engineering, and Materials Science and Engineering.

Table 1. Components of the Practice Oriented Masters Program

Engineering Component	*Electronics packaging focus*	12 semester hours
	Fundamental courses	12 semester hours
Management Component	6 semester hours	
Internship Component	3 months for domestic 6 months for international	

The engineering component focuses on systems-level understanding and hands-on laboratory experience in microelectronics packaging, coupled with fundamental scientific knowledge in order to address manufacturing and short-term development issues in the electronics industry. The management component consists of two courses and focuses on business basics that a practicing engineer should know, including accounting, finance, organizations and strategy, marketing, and operations. The internship is the most unique aspect of this program and provides future engineers with professional experience early in their careers.

3 CURRICULUM

3.1. Electronic Packaging Focus

As shown in Table 2, an Electronic Packaging focus requires students to take twelve semester hours (four three-credit courses) from a list of approved packaging courses. Two out of the four courses are core courses and restricted to a system-level course (ECE/ME/MSE 6776) and either of the two "Design, Build and Operate" (DBO) courses. The other two courses are electives and chosen among a list of approved elective courses with significant electronic packaging content (see Table 3).

The system-level course, *ECE/ME/MSE 6776-Microelectronics Systems Packaging Technologies*, is a cross-disciplinary microelectronics packaging course that reviews and discusses microelectronic packaging technologies for consumer, computer, telecom and automotive systems. It integrates various disciplines including electrical, materials, chemical and mechanical engineering and is designed to be an

advanced introductory course for graduate students in ECE, ME, MSE, Physics, and Chemistry. The course provides both fundamental and applied aspects of packaging technologies that have been derived from ten years of research advancements in the PRC.

Table 2. Requirements for the Electronic Packaging Focus

Course Type	**Course Title**	**Credits**
System-level	ECE/ME/MSE 6776 - *Microelectronics Systems Packaging Technologies*	3 semester hours
Hands-on DBO courses	ChE/ECE/MSE 4755 – *Electronic Packaging Substrate Fabrication* ----------OR---------- ME/ECE/MSE 4754 - *Electronics Packaging: Assembly, Reliability, Thermal Management and Test*	3 semester hours ---------- 3 semester hours
Electives	2 courses from the elective course list	6 semester hours
TOTAL	**4 courses**	**12 semester hours**

A key aspect of the POM program's packaging education objective is to provide students with hands-on "design, build and operate" opportunities that reach beyond traditional classroom learning. Thus, two-part sequence hands-on instructional lab courses that expose students to basic packaging concepts and techniques have been developed. These courses focus on: (1) substrate fabrication and (2) assembly, reliability, thermal management, and test [3, 8]. Each course includes lectures but weighs heavily on laboratory exercises that permit students to design, build, assemble and test electronic packages. The substrate fabrication lab course includes topics such as interconnect design, dielectric deposition, via formation, metallization, and substrate testing. The module assembly course covers flip chip assembly, functional test, reliability modeling, and thermal management. The unique feature of the DBO course sequence is that it encompasses electrical engineering, mechanical engineering, chemical engineering, and materials science and engineering concepts. Both of the DBO courses are held at the Center's advanced packaging systems prototype facilities (shown in Figures 1 and 2) which houses state-of-the art equipment. These courses enable students to appreciate current technologies that are being utilized to develop high-quality packaging substrates for electronics.

Table 3. List of Elective Courses with Electronic Packaging Content

Packaging Elective Courses		
ChE6610–Polymers in Microelectronics	ECE6455–Semiconductor Process Control	ECE6458–Gigascale Integration
ECE6140–Digital Systems Test	ECE6458–Gigascale Integration	ME6124-Finite Element Method
ECE6360-Microwave Design	ECE6520–Integrated Optics	ME6224–Semiconductor Manufacturing and Assembly
ECE6361–Microwave Design Laboratory	ECE6542–Optoelectronics	ME7228–Thermomechanical Reliability in Packaging
ECE6380-Int to Computational Electromagnetism	ECE7140-Advanced Digital Systems Test	MSE6510–Polymers for Electronics and Photonics I

The contents of the packaging courses are updated regularly to integrate breakthroughs, advances, developments, and research results into the curriculum. Hence, we were told by our industry members that the packaging focus demonstrates a critical level of packaging expertise to employers.

Figure 1 – Substrate Fabrication Lab

Figure 2 – Module Assembly Lab

3.2. Management Component

The management component focuses on management of technology (particularly aimed at achieving national roadmap goals), entrepreneurship, and global aspects of the packaging enterprise. Students are required to take two courses (one core course and one elective) to complete the management component (see Table 4).

Table 4. Requirements for the Management Component

Course Type	Course Title	Credits
Core course	MGT6753-Management for Engineers	3 semester hours
Elective course	1 course from the list of elective courses	3 semester hours

The basic management concepts are introduced to the students in the *MGT6753-Principles of Management for Engineers* course. The course consists of modules that are designed to provide the engineering student with basic, generalized management skills. Each module is one to three weeks long and is taught by a faculty who is an expert in that area. The elements are drawn from the business basics of the MBA program, repackaged in shorter increments that sample the field for the engineer. The goal is to transmit the language and the "look and feel" of each area, so that the POM engineer can talk and team effectively with his or her colleague in a cooperate environment. The second course in the management component is an elective that each student chooses from among a number of alternatives. Students are encouraged to excel in one of the module topics that they are exposed to in the MGT6753 course.

3.3. Internship Component

The internship component plays an important role in preparing the students for the global electronic packaging industry. During the internship, the POM students learn about electronic packaging manufacturing and cost analysis. They also receive training in solving specialized packaging problems by

working on a specific packaging project and by preparing a project report for presentation when they return. At present, the PRC has 29 industry members (8 of them international) and about 50 industrial affiliates. These industrial relationships have been the foundation to identify the domestic and international internship sites for the POM students. We expect the international internship period to be longer than the domestic and last up to 6 months. Part of this time is spent for improving the language skills and getting familiar with foreign cultures.

4 PROGRAM IMPLEMENTATION

The Practice-Oriented Masters program is funded by a grant from the National Science Foundation, Engineering Education and Centers Office, through Georgia Tech's Packaging Research Center, in fall 1998. The first 9 months were dedicated to the development of the curriculum and student recruitment. During that time, the PRC Industrial Advisory Board (IAB) Education Committee worked together with the program administrators and helped the development of the individual components of the program and the contents of the courses. Once the curriculum was established, the POM program was submitted for approval in the participating engineering schools: Electrical and Computer, Mechanical and Materials Science and Engineering. By September 1999 the program was approved and the DBO courses were cross-listed at all three of the mentioned engineering schools

The first group of 6 POM students entered the program in August 1999. During the following years on the average 6 students were admitted every fall. All the POM students became and integral part of the Center and attended the monthly seminar, industry advisory board meetings and social events. Currently 12 students are enrolled in the program. All the 30 students admitted in the past 5 years were recent BS recipients and received their degrees either from electrical engineering, mechanical engineering, materials science and engineering or physics. Among these thirty students, eleven of them successfully completed all the components of the program within two years and received their degrees and certificates. Four of the eleven graduates are currently enrolled in the Ph.D. program at Georgia Tech and the rest are employed in the packaging industry. Seven out of 30 admitted students were not able to receive the POM certificates though they received their degrees. Two of them dropped out of the program and the other five could not complete either the internship or the management component. However, all five students completed the packaging focus requirements and are currently employed by the electronic packaging industry.

Overall there is limited financial support for the POM students and it is difficult for them to absorb the costs. This is one of the drawbacks of the program. Since majority of the students participating in the POM program are in the non-thesis MS track they do not get graduate research assistantships. A few of them are graduate teaching assistants and they receive tuition waiver and stipend. In order to attract more students, the POM program offers a limited amount of scholarships for the in-state tuition assistance, ranging from up to $4,000 to $8,000 per academic year to U.S. citizens and permanent residents. However, very recently PRC was successful in establishing "Cooperate Fellowships" with some of the electronic packaging companies. The companies are asked to provide full support (up to $25,000 per year) to one student each year. In return, the students supported by the corporate fellowships are expected to do the internship component of the program at the sponsoring company.

5 PROGRAM ASSESSMENT

On-going assessment is a crucial component of any educational program and since 1999 the Packaging Research Center has been conducting assessments to assure that the developed program is as educationally effective as possible. The assessment methods are identified, developed, and implemented in collaboration with the Georgia Tech Office of Assessment.

Over the past three years the POM students have been asked to take part in the evaluation of the program. All POM students are asked to participate in three evaluations. First, students are asked to complete exit surveys during their last semester at Georgia Tech. Second, in-depth interviews of POM students are conducted twice during their tenure in the program; one at the end of their second semester and again during their final semester. Third, internship employers are asked to complete evaluations of the students interning in their organization.

When responding to the exit survey, students rated the PRC quite highly in all areas assessed. Students were very positive about their experiences with the program and the degree to which they were trained in microelectronics packaging. Students felt they were well prepared to compete both professionally in their discipline and obtain employment upon graduation. These sentiments were mirrored in the responses they made during the interview process. .

In general, POM students reported having many positive experiences due to their participation in the program. Many of the main objectives for this program are being met; and summary of student responses are provided below.

- Students felt that they were well prepared in the area of microelectronics packaging. They stated being relatively comfortable with microelectronics fundamentals and tacking packaging-related problems.
- Students cited many areas other than course work that have contributed to their knowledge in microelectronics packaging. Students commented on the internship program, the seminars and presentations held at the PRC, and interactions with students from other major fields than their own.
- Students responded that they had extensive experiences in multidisciplinary teams and were able to work on technologically advanced equipment.
- Students responded that they had good exposure to contemporary and professional issues.
- Students felt that their technical writing and presentation skills were enhanced either through the program itself or through the courses in the program.

Additionally, as part of the evaluation of the POM program the internship supervisors are asked to compete a survey instrument that asks questions pertaining to their experiences with the POM students. As can be seen in Figures 3 to 6, the internship employers rated the POM students quite highly. The response scale for Figures 3 through 5 is: 5 = Very well prepared to 1 = Not prepared. The response scale for Figure 6 is: 5 = Extremely important to 1 = Not important.

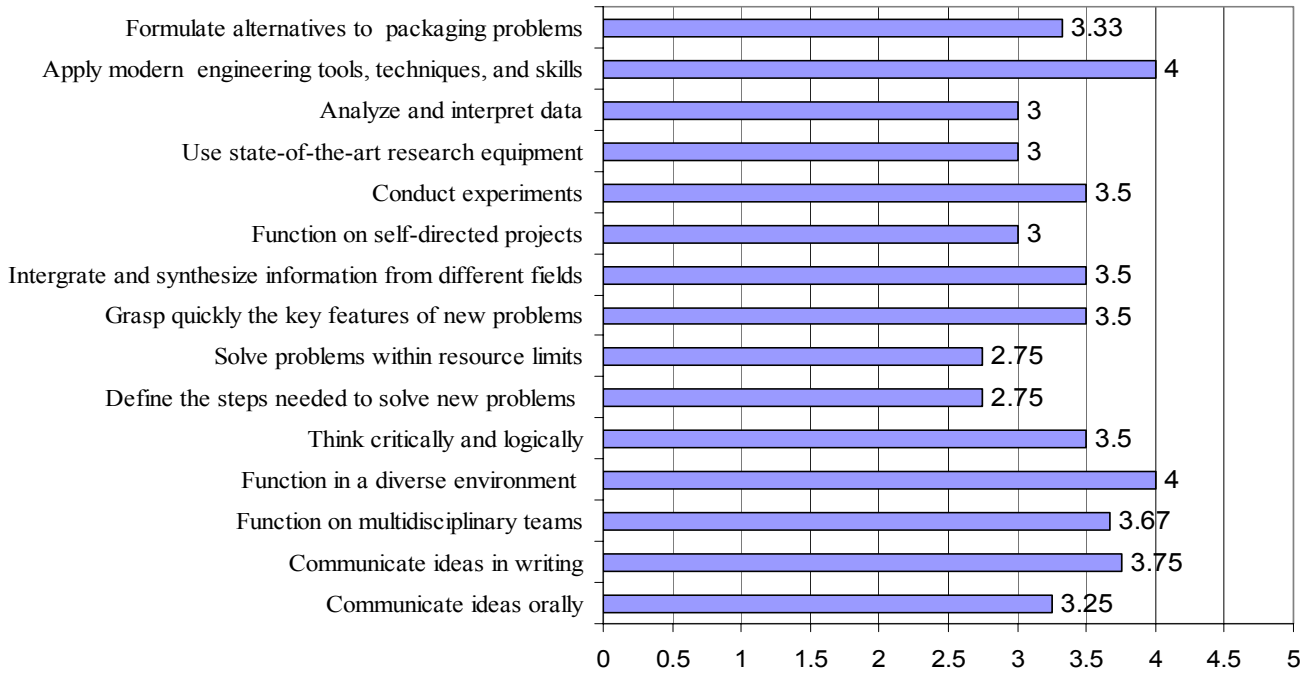

Figure 3 – Industry Respondents Perception on the Understanding and Abilities of the POM Interns

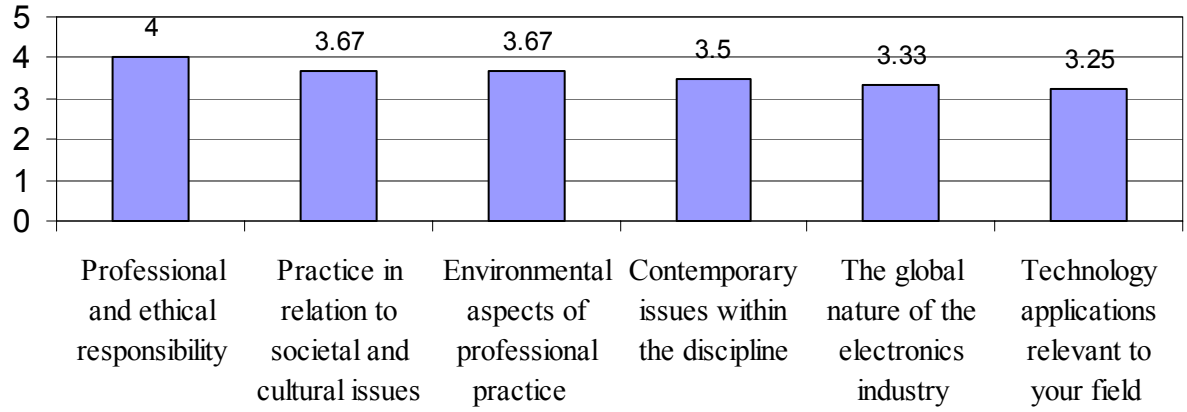

Figure 4 – Industry Respondents Perception on the POM Interns Understanding of the Professional Issues

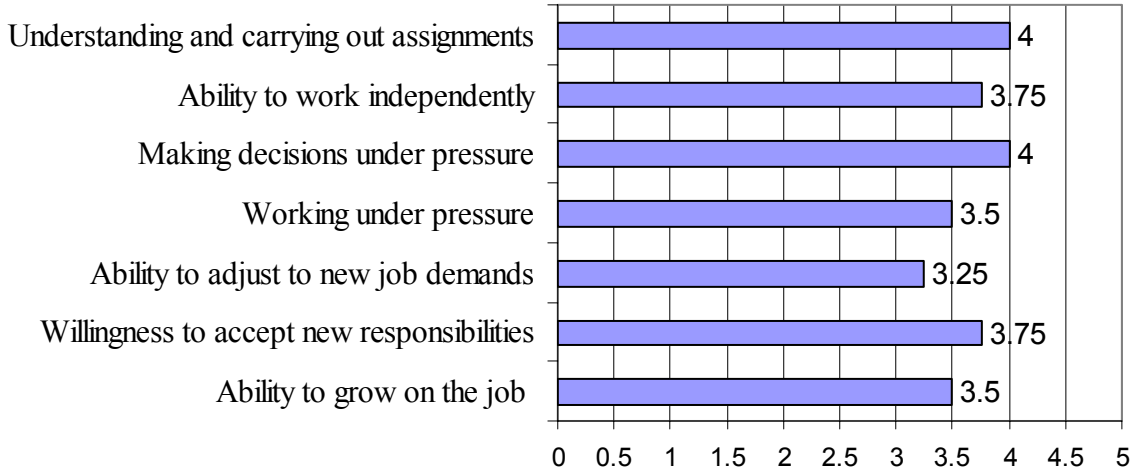

Figure 5 – POM Interns Work Attitudes and Skills

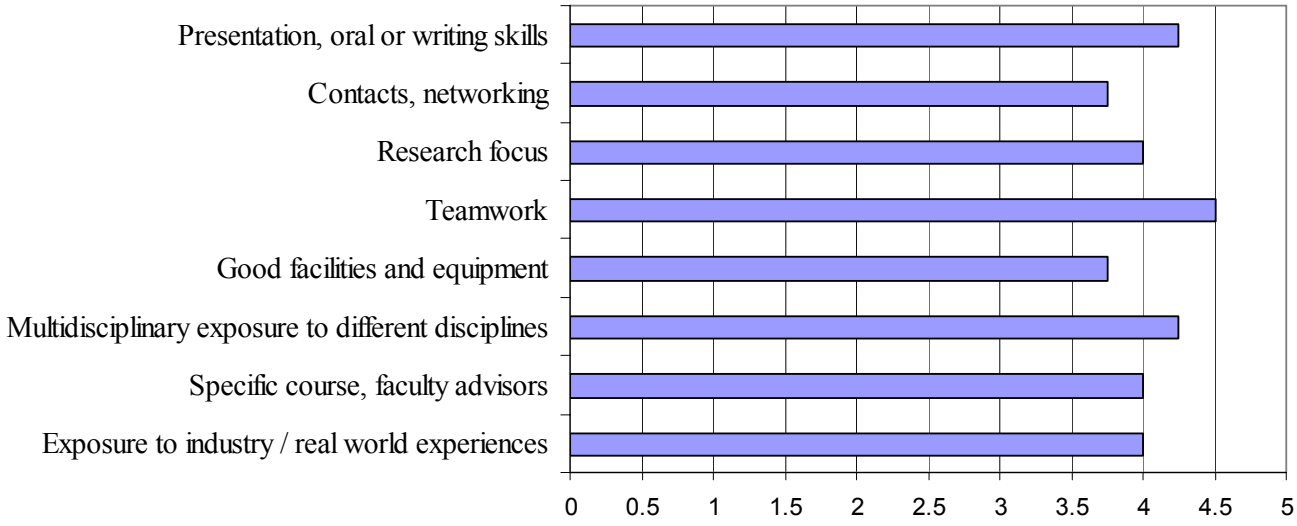

Figure 6 – Industry Responses for the Career Impact of the Students due to POM Education

In summary, it is apparent that students are very satisfied with the education and training they are receiving in the Packaging Research Center. Continual use of all evaluation procedures is critical to program development and the information provided through the exit surveys and interviews will enable both the faculty members and the administration at the PRC focus its efforts on areas within the program

that are in need of attention. In addition, evaluation findings can be used to designate funding to the appropriate areas to further enhance the students' experiences. Finally, the continued use of the internship employer survey will help focus the evaluation by providing external information about the PRC program and services.

6 CONCLUSIONS

Historically, engineering graduate students emerge from universities with a somewhat narrow set of skills, and many of these students lack a more global and comprehensive system-level technology perspective as well entrepreneurial skills. The proposed solution to this state of affairs at Georgia Tech's microsystems Packaging Research Center has been the development of an interdisciplinary Practice-Oriented Master's certificate program. This program provides an intrinsic connection between the needs of industry and the education of students. The students enrolled in the program receive training in engineering, management, and practical aspects of microelectronic packaging technology. The engineering component focuses on system-level and lab-based microelectronic packaging education. With the recent development of a world class prototype facility at the PRC, now a truly unique opportunity exists to offer the hands-on courses that encompasses the complete product development cycle, starting from systems-level product design, on through electrical and mechanical design and finally functional prototyping of electronics/electromechanical systems. In order to attract more students to the POM program, the PRC has recently requested packaging industry's help to sponsor students' education through corporate fellowships.

In summary, the entrepreneurial and practice-oriented Masters program described above has three components that focus on, (1) theory and practice in microelectronic systems technology, (2) management of technology to serve the global market place, and (3) industry internships that expose the students to the industry (http://www.prc.gatech.edu/academics/pom.htm). It is the first program of its kind and expected to be widely accepted among other universities around the world

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