Identify and Compare Knowledge, Skills, and Abilities Needed in Semiconductor Graduate Education from an Academic and Industrial Perspective

Prof. Nathan Jackson, University of New Mexico

Prof. Jackson is an Associate Professor in Mechanical Engineering and Director of the Nanoscience and Microsystems Engineering Graduate Program at University of New Mexico. He is the PI of an NSF funded Innovation and Graduate Education project focused on increasing job readiness of graduate students in the semiconductor industry. He is a member of ASEE and Senior Member of IEEE. He was awarded the Regents Lecturer Award in 2025, Harrison Faculty Award for Excellence in Service, Engineering Research Faculty Award, and Junior Faculty Research award at ASEE-GSW in 2022, and is an NSF Career Awardee in EPMD on Energy Harvesting. He has more than 150 journal publications and over 20 patents.

Dr. S. Pil Kang, University of New Mexico

Dr. S. Pil Kang is an Associate professor and Director of Orgniazation, Information, and Learning Sciences (OILS) program at the University of New Mexico. His academic interests include change management, organizational citizenship behavior (OCB) in education, social capital, and collaborative learning. He may be reached at pilkang@unm.edu

Nisansala Bandara, University of New Mexico

Nisansala Bandara is a PhD student in the Organization, Information, and Learning Sciences (OILS) program at The University of New Mexico. Her research focuses on organizational behavior, employee well-being, workplace learning, and instructional design in STEM education. Her current work primarily examines neurodiversity in workplace settings, particularly the experiences of neurodivergent employees in STEM fields. Drawing on seven years of professional experience with the United Nations, she brings practitioner insight to her scholarly work and seeks to bridge theory and practice to foster more inclusive and adaptive workplaces and learning environments.

Mr. Matthias W Pleil, University of New Mexico

Matthias Pleil, Ph.D., is the Director of the Manufacturing Engineering Program and the Manager of the MTTC Cleanroom at the University of New Mexico. He has participated in several NSF grants focusing on microfabrication education for 2-year, 4-year, and graduate-level students. Additionally, Dr. Pleil holds the position of Research Professor and Senior Lecturer III in Mechanical Engineering, where he instructs several undergraduate engineering courses and champions the field of micro and nanotechnology. Dr. Pleil possesses over 12 years of experience in Semiconductor Manufacturing, having worked at both Texas Instruments and Philips Semiconductors. His roles included Senior Process and Equipment Engineer and Engineering Manager in Photolithography, Yield, and Metrology. He earned his Ph.D. in Physics in 1993 from Texas Tech University, where he conducted original research on Time-Resolved Fluorescence Spectroscopy.

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Abstract:

There is a high demand to increase job readiness in the semiconductor/microsystems manufacturing area, especially for graduate students (MS/PhD) as they are expected to add value to the company much sooner than undergraduates who typically require longer onboarding times. The difference in onboarding time causes the knowledge, skills, and abilities (KSA) to be significantly different between undergraduates and graduate students. Current engineering graduate academic education is focused on enhancing research experience such as technical writing, experimentation, and research methodology; however, it does not fully prepare students for industrial work experience. Therefore, graduate students often struggle with transitioning from an academic setting (research oriented) to an industry environment, because students and most faculty have limited industrial work experience. This study aims to identify key KSA that graduate students going into the semiconductor industry are expected to have so that new pedagogical methods can be implemented in future course development. A survey was given to both semiconductor industry members and Engineering Faculty members, to perform a comparison study between what industry needs and what academics think they need. KSA topics included essential skills, technical skills, fabrication skills, design knowledge, statistics, emerging skills, and management. The survey allowed the panel to state what KSA were important and what KSA they thought Universities already do a good job of teaching to graduate students. The results demonstrate that the industry panel identified 40.4% of the KSA that were surveyed as important and currently lacking in recent graduate student hires. The survey illustrated that 59.6% of potential KSA were deemed either not critically necessary or new employees already had these traits, meaning universities already do a sufficient job of teaching these KSA to students. However, academics said 58.33% of the KSA were needed and not currently taught. This shows a strong perceptual difference between what academics think industry members need and what industry members consider necessary. The paper identifies and compares key KSA and demonstrates which ones had strong prioritization gaps between academia and industry members. The results of this study will be beneficial to faculty in developing new pedagogical methods to better prepare students for transitioning from academia to the semiconductor industry and demonstrate a strong need for industrial opinion when designing curriculum.

Introduction:

The semiconductor and microelectromechanical systems (MEMS) manufacturing industry is rapidly expanding and in desperate need of quality employees as companies attempt to bring advanced manufacturing back to the USA. Since this area is considered, high technology manufacturing a lot of the vacant jobs are for students with graduate degrees due to the complexity of micro/nano fabrication. However, semiconductor industry members are finding it hard to hire quality students with the necessary skills to add value to the company right away, and they are finding that majority of graduate students do not have the desired Knowledge, Skills, and Abilities (KSA) needed to accomplish this task. Therefore, there is a high demand to not only alter KSA being taught but also the method of which they are being taught, to enhance job readiness for graduate students. There have been numerous attempts to increase job readiness for technicians and undergraduates in this area [1-3] but little research has been investigated to enhance graduate education in this area [4-6].

Methods to enhance job readiness in advanced manufacturing have mostly focused on cleanroom and microfabrication training [7-10], which is needed. However, the authors talked to former students and colleagues that now work in the semiconductor industry and discovered that most of them thought recent graduate students were lacking the necessary skills. KSA have been investigated for years in numerous industries and used as a useful tool to enhance engineering education. There have been KSA studies for the semiconductor manufacturing area, but all of them focused on undergraduate and technician education [11-13]. Graduate (MS/PhD) students are expected to add value to the company much sooner than technicians and likely will have different KSA. Undergraduates and technicians are expected to have longer onboarding periods, whereas MS/PhD hires are expected to have the KSA to make a significant impact early into their careers.

Most engineering faculty have a traditional academic background (BS->MS->PhD->Post-Doc->Faculty) where they have limited experience with industry, this makes it challenging for them to know what KSA are desired from industry. The semiconductor industry is evolving at a rapid rate and KSA is continuously changing. Graduate students typically get more hands-on and technical experience during their thesis research work, but these skills are geared towards academic careers as those are the skills that their faculty mentor know best [15].

Most graduate students will go on to have industrial careers not academic ones, so industry members are the end customers and students are the products for academics. Therefore, academics need to modify the product to meet current demands from the customer. Industries have identified that the best method for students to gain the KSA that are needed is through internships [16, 17]. However, internships are not always possible for graduate students due to location, research time constraints, citizenships, and academic time commitments, and therefore academics need to find methods to implement the KSA into the curriculum. Recently there have been numerous studies focused on enhancing semiconductor pedagogy but the first step needed is to identify what KSA are needed so that academics can implement these into the courses [5, 9, 18, 19].

In this paper the authors investigate methods to identify key KSA from both semiconductor industry members and engineering faculty members perspective. Both perspectives were investigated to compare and identify any perceived differences between industry needs and what academics think they need. The investigation included a detailed survey of numerous potential KSA identified by industry, academics, and previous research. The potential KSA were placed in categories including essential skills, technical skills, fabrication skills, design knowledge, statistics, emerging skills, and management. The survey was completed by senior hiring industry members as well as academic faculty working in semiconductor research. The methodology and results of the survey are described in detail, and the results are discussed to determine what KSA are currently desired by a panel of industry members. These KSA can then be used in future curriculum development to enhance semiconductor graduate education programs.

Industry and Faculty Panels:

The authors have previous experience in enhancing job readiness for technicians and undergraduates in the semiconductor industry [20, 21] and have significant experience in developing novel labs for MEMS graduate education [22] as well as developing online videos on microfabrication on various platforms such as YouTube designed to supplement lectures [23]. The authors have >20 years of industry experience in semiconductor/MEMS manufacturing and thus used their prior experience to help identify potential KSA. There has been numerous studies identifying key KSA for engineering education to enhance job readiness in various fields [24, 25], but KSA in the manufacturing semiconductor field are limited.

An industry panel was initially formed which consisted of members from the semiconductor/Microsystems industry. The panel consisted of n=10 members with varying employment history and job titles ranging from process engineer to CTO and consisted of members from large multinational companies to small startup companies. All industry members have at least five years of experience in semiconductor manufacturing industry and have experience in hiring and training new employees. The panel consisted of members from different regions in the USA, so they were not influenced by employees from a single university. The initial role of the industry panel was to develop potential KSA that should be included in the survey, which identify key KSA that industry members believe new hires at the MS/PhD level should have to add value to the company without significantly long onboarding times. The authors also participated in identifying potential KSA based on their vast work experience and previously identified KSA for technicians and undergraduates identified by the Micro Nano Technology Education Center (MNT-EC) [12, 13]. After discussions n=47 potential KSA were identified as being worth including in the survey to be sent to both academics and various semiconductor industry members.

Survey Methodology:

A survey consisting of the n=47 KSA was created and sent out to various semiconductor industry members having the same credentials as listed above as well as various faculty members from different universities in all regions of the USA. The KSA were grouped into six categories shown in Table 1 consisting of essential skills, technical skills, fabrication skills, design, statistics and yield, and emerging skills and management.

Panelists were asked to score each potential KSA on a 1-4 scale, where a score of 4 indicated a strongly needed KSA that majority of recent hires do not possess, a score of 3 indicated the KSA was needed but not highly needed, a score of 2 represented the belief that universities already do a good job of teaching students these KSA (in other words these KSA were needed but recent hires possessed these KSA), and a score of 1 meant these KSA were not needed in the semiconductor manufacturing industry.

Table 1: Survey Questions and Categories

Question (#)	Sample Questions (shortened)
	ESSENTIAL SKILLS
1	Verbal Communication:
2	Presentation Communication:
3	Respect: Valuing diverse perspectives, treating colleagues with respect, etc..
4	Emotional Intelligence: The awareness and management of one's own emotions, etc...
5	Trust: Best practices in building and maintaining trust among teammates
6	Conflict Resolution: Managing and resolving disagreements or conflicts in a constructive manner
7	Accountability: Taking responsibility for one's own work
8	Effective Team Leadership Skills - Providing assistance and motivation to team members
9	Internal written communication: (weekly reports, passdowns, emails)
10	Customer based communication: (technical papers, standard operating procedures, project reports)
11	Engineering Notebook: Effective documentation and record of work and a way to track progress.
12	Time Management: The skill of effectively managing various tasks and responsibilities.
13	Lifelong Learning: Continually updating skills and knowledge
14	Creativity and Innovation: Thinking outside the box to develop new solutions
	TECHNICAL SKILLS
15	Equipment Maintenance and Calibration:
16	Troubleshooting: Process engineering issues
17	Quality Control: Implementing and monitoring quality control measures
18	Optimization: of process development
	PROCESS FABRICATION SKILLS
19	Photolithography:
20	Soft Lithography:
21	Wet Etching:
22	Dry Etching:
23	Metrology:
24	Chemical Vapor Deposition (CVD)
25	Physical Vapor Deposition (PVD)
26	Oxidation:
27	Doping
28	Dicing
29	Microelectronics packaging:
30	Quality Control (QC) process engineering
	DESIGN
31	Mask design (CAD)
32	Finite Element Analysis (FEA)
33	Design Rules in micro and nano fabrication refer to a set of guidelines and constraints
	STATISTICS & YIELD
34	Device testing (probe testing)
35	Fault detection
36	Gauge studies, also known as gauge repeatability and reproducibility (R&R) studies
37	Statistical Process Control (SPC)
38	Process Capability Index (Cp) and the Process Capability Performance Index (Cpk)
39	Statistical software like JMP, Minitab, and SPC (Statistical Process Control)
40	Design of Experiments (DOE)
41	Failure Modes and Effects Analysis (FMEA)
42	Decision-making using the Pareto principle, often referred to as the 80/20 rule
	EMERGING SKILLS & MANAGEMENT
43	Ethical use of AI-assisted analysis:
44	IP (Intellectual Property), security, and non-disclosure considerations
45	Industry culture differences to Academics
46	Project management
47	Budgets

The survey was sent out to numerous semiconductor manufacturer engineers as well as academic faculty that perform relevant research and have graduated a student that have gone on to work in semiconductor area within the last 5 years. The industry members surveyed all met the above criteria and consisted of members from all regions of the USA, and from large multinational companies to small startup companies. The purpose of the faculty members taking the survey was not to influence key KSA (which will be determined from the industry member surveys), but instead to determine if academics understood what their customers wanted. Bridging the gap between academia and industry is critically important for engineering education and to enhance education academics need to understand their needs. The objectives of the study include:

1. Determine key KSA desired by semiconductor manufacturing industry for new hires with a MS or PhD degree.
2. Determine if academic faculty understand what KSA are desired by semiconducting manufacturing industry members for MS/PhD students.

Results and Discussion:

The survey had an acceptance rate of ~25% (n=36) for industry members and ~35% (n=14) for academic faculty. The survey results of KSA from the industry members surveyed are shown in Figure 1. A cutoff threshold score of 3.25 was identified by the initial panel. Anything scoring >3.25 was considered an essential KSA that current hires were lacking. The threshold was set by the industry panel after all members discussed what the threshold should be. Surveys were evaluated and analyzed by the authors and discussed with the industrial panel.

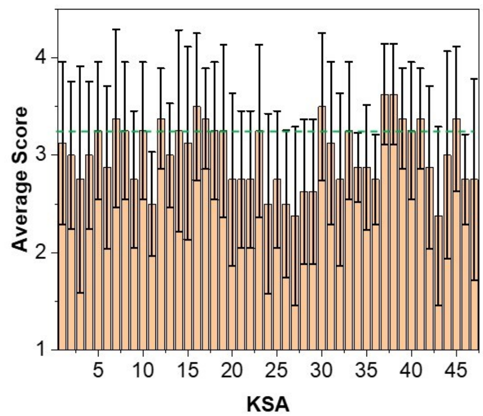

Figure 1- Average scores from the industry survey of the 47 KSA surveyed, where the green dashed line represents the threshold for highest ranked scores and the error bars represent a standard deviation.

The industry member panel identified 19 out of the 47 (40.4%) potential KSA that were surveyed as important and currently lacking in new employees (>3.25 score). The data also shows that 59.6% of potential KSA were deemed either not necessary or that new employees already had these skills, meaning universities already do a sufficient job of educating students with these KSA. A detailed breakdown of the results from various categories is given below in Figure 2. There were four KSA's that scored above a 3.5 which were deemed critically necessary, which included Troubleshooting microfabrication issues (Technical Skill), Quality Control (Fabrication Skills), Statistical Process Control (SPC) (Statistics), and Process Capability Index (Cp) and Process Capability Performance Index (Cpk) (Statistics). Every surveyed industry member scored each of these four KSA with a score of 3 or 4, meaning they were important to everyone who was surveyed, and everyone thought students do not currently have those KSA. The survey also determined that 44.6% of the potential KSA scored <3 meaning a significant amount determined that students already had these skills.

The standard deviations for some of the KSA were quite large for instance the topic of Creativity had a standard deviation of >1 as some industrial panels gave it a 2 saying students already had it while others scored it as a 4. The large standard deviations are likely caused by different needs from various companies, as small medium enterprises (SME) needs can be different from multinational companies. For instance, startup companies might want students to have more creativity as they would be working in R&D more than multinational companies, where they might need more creativity. In the future a more detailed survey could be conducted and could be separated based on size and job of the company. Another reason for the high standard deviation could be the low acceptance rate of the survey, which could be increased to help reduce the standard deviation.

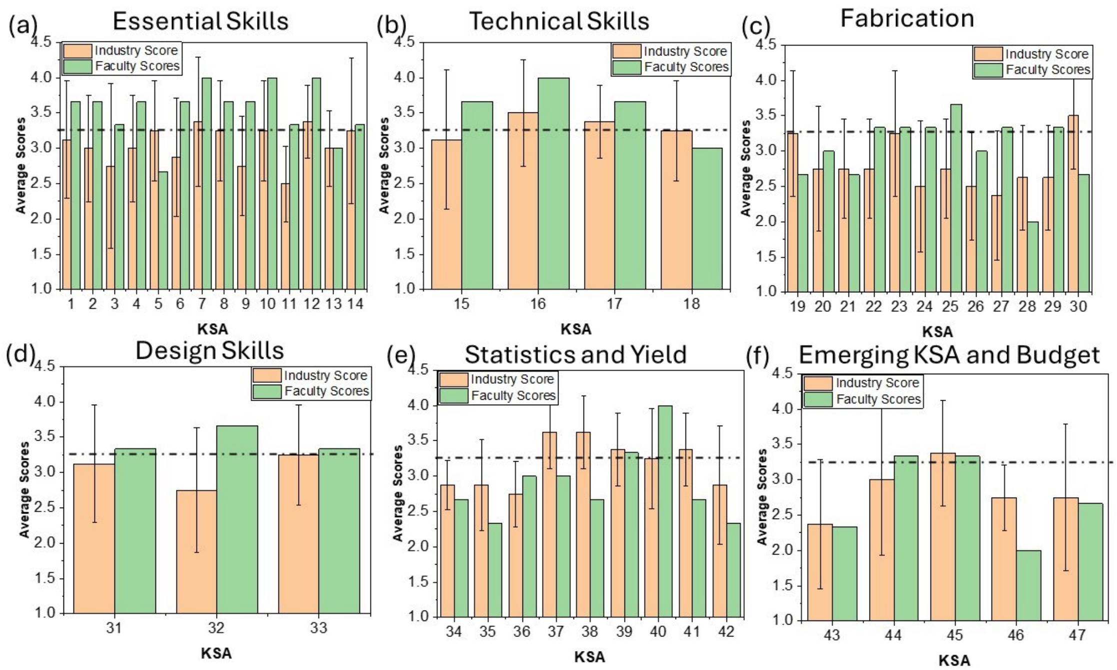

Figure 2- Average scores from both industry and faculty panel of the 47 KSA's surveyed, broken down into categories where the green dashed line represents the threshold for highest ranked scores and the error bars represent the standard deviation.

The results from the industry panel and faculty panel KSA survey were broken down into various categories as shown in Figure 2. First, it was shown that each category had at least one KSA that the industry panel deemed necessary, but the categories that had the highest number of KSA above the threshold were Essential skill, technical skills, and Statistics and Yield. The results of the survey demonstrate that 42.9% of the essential skills, 75% of the technical skills, 25% of the fabrication skills (as universities already train students well in these categories), 33.33% of Design, 55.5% of Statistics, and 20% of emerging skills were necessary.

Figure 2 also shows the results from the faculty panel on the same survey. The results show large differences as the KSA that faculty thought were important were either not important or industry members find students already possess. For instance over the past couple of decades there has been a strong push to increase essential skills to increase job readiness [26, 27], and while our industry members still highlighted that 42.9% of the KSA topics in this category were still lacking, they thought that students typically had the majority of the essential skills that were necessary for the job. This is good, as it demonstrates that academics have made significant progress at enhancing essential skills over the past two decades and students are now sufficient in these topics including verbal and written communication, dealing with conflicts, presentation skills etc. However, an interesting observation was that faculty scores for essential skills were significantly higher meaning faculty still believe that students need to enhance their essential skills further, as the faculty panel identified 85.71% of the KSA in this category to be above the threshold, which is significantly higher than the 42.9% identified by the industry members. Therefore, this shows that faculty members do not necessarily know what industry is demanding, which is the reason why students are not getting the correct KSA as desired by industry. Over the past decade or two there has been a big push to increase essential skills in students and based on industry demands it appears this has worked. In the essential skills category faculty and industry only agreed on 35.7% of the categories (including team leadership skills, accountability, time management).

Table 2: Necessary KSA determined from Industry and Faculty

Question (#)	Sample Questions (shortened)	Industry Important KSA (survey results)	Faculty thinks KSA (survey results)
	ESSENTIAL SKILLS		
1	Verbal Communication:		X
2	Presentation Communication:		X
3	Respect: Valuing diverse perspectives, treating colleagues with respect, etc..		X
4	Emotional Intelligence: The awareness and management of one's own emotions, etc...		X
5	Trust: Best practices in building and maintaining trust among teammates	X	
6	Conflict Resolution: Managing and resolving disagreements or conflicts in a constructive manner		X
7	Accountability: Taking responsibility for one's own work	X	X
8	Effective Team Leadership Skills - Providing assistance and motivation to team members	X	X
9	Internal written communication: (weekly reports, passdowns, emails)		X
10	Customer based communication: (technical papers, standard operating procedures, project reports)	X	X
11	Engineering Notebook: Effective documentation and record of work and a way to track progress.		X
12	Time Management: The skill of effectively managing various tasks and responsibilities.	X	X
13	Lifelong Learning: Continually updating skills and knowledge		
14	Creativity and Innovation: Thinking outside the box to develop new solutions	X	X
	TECHNICAL SKILLS		
15	Equipment Maintenance and Calibration:		X
16	Troubleshooting: Process engineering issues	X	X
17	Quality Control: Implementing and monitoring quality control measures	X	X
18	Optimization: of process development	X	
	PROCESS FABRICATION SKILLS		
19	Photolithography:	X	
20	Soft Lithography:		
21	Wet Etching:		
22	Dry Etching:		X
23	Metrology:	X	X
24	Chemical Vapor Deposition (CVD)		X
25	Physical Vapor Deposition (PVD)		X
26	Oxidation:		
27	Doping		X
28	Dicing		
29	Microelectronics packaging:		X
30	Quality Control (QC) process engineering	X	
	DESIGN		
31	Mask design (CAD)		X
32	Finite Element Analysis (FEA)		X
33	Design Rules in micro and nano fabrication refer to a set of guidelines and constraints	X	X
	STATISTICS & YIELD		
34	Device testing (probe testing)		
35	Fault detection		
36	Gauge studies, also known as gauge repeatability and reproducibility (R&R) studies		
37	Statistical Process Control (SPC)	X	
38	Process Capability Index (Cp) and the Process Capability Performance Index (Cpk)	X	
39	Statistical software like JMP, Minitab, and SPC (Statistical Process Control)	X	X
40	Design of Experiments (DOE)	X	X
41	Failure Modes and Effects Analysis (FMEA)	X	
42	Decision-making using the Pareto principle, often referred to as the 80/20 rule		
	EMERGING SKILLS & MANAGEMENT		
43	Ethical use of AI-assisted analysis:		
44	IP (Intellectual Property), security, and non-disclosure considerations		X
45	Industry culture differences to Academics	X	X
46	Project management		
47	Budgets		

These differences in opinion are shown in several of the categories, for instance statistics and yield, which scored two of the highest values from industry members (37 and 38) which scored below the threshold for faculty (meaning faculty either that these were not important or that students had these skills). This illustrates that the KSA that industry thought were important, were not deemed important by faculty. Future studies will focus on increasing the number of panel members to get a better statistical analysis, but initial results demonstrate that academic faculty have a different perception of what industry actually desire from new employees with MS or PhD. One KSA identified in the emerging section as important was students understanding of cultural differences between academia and industry. The main causes of this are believed to be a) academics skills and culture are different from industry and b) most faculty do not have industry experience, so it is difficult for them to provide industry related skills. However, a skill that new students tend to have that both industry and faculty deemed not necessary was generative AI.

Table 2 illustrates the potential KSA and the ones with >3.25 threshold determined by both industry members and academic faculty. The results demonstrate that industry and faculty agreed on 48.9% of the potential KSA topics, this shows most of the time academics and industry members disagreed on rather a particular KSA was necessary or not. Table 3 shows the 19 potential KSA that the surveyed deemed to be critically important and that majority of students do not possess. These should be areas that academics focus on in future curriculum development or research mentoring.

Table 3: Identified key KSA that are essential for Semiconductor Manufacturing Industry

Question (#)	KEY KSA IDENTIFIED
	ESSENTIAL SKILLS
5	Trust: Best practices in building and maintaining trust among teammates
7	Accountability: Taking responsibility for one's own work
8	Effective Team Leadership Skills - Providing assistance and motivation to team members
10	Customer based communication: (technical papers, standard operating procedures, project reports)
12	Time Management: The skill of effectively managing various tasks and responsibilities.
14	Creativity and Innovation: Thinking outside the box to develop new solutions
	TECHNICAL SKILLS
16	***Troubleshooting: Process engineering issues***
17	Quality Control: Implementing and monitoring quality control measures
18	Optimization: of process development
	PROCESS FABRICATION SKILLS
19	Photolithography:
23	Metrology:
30	***Quality Control (QC) process engineering***
	DESIGN
33	Design Rules in micro and nano fabrication refer to a set of guidelines and constraints
	STATISTICS & YIELD
37	***Statistical Process Control (SPC) ***
38	*** Process Capability Index (Cp) and the Process Capability Performance Index (Cpk) ***
39	Statistical software like JMP, Minitab, and SPC (Statistical Process Control)
40	Design of Experiments (DOE)
41	Failure Modes and Effects Analysis (FMEA)
	EMERGING SKILLS & MANAGEMENT
45	Industry culture differences to Academics
	* representing critically necessary KSA*

Conclusion and Summary:

In conclusion, the paper demonstrates results from a comparison survey to identify key KSA in the semiconductor manufacturing area determined by current industry demands for MS and PhD students. The survey was also conducted by academic faculty performing research in the area, and the results were compared to determine if academics had a good understanding of what industry needs were. Nineteen of the 47 potential KSA were deemed necessary with four KSA being identified as critically necessary. The paper also identified that faculty had a perceptual difference of KSA compared to industry. On the other hand, the industry survey also identified key areas where they think universities do a good job teaching the KSA, such as fabrication knowledge (theory) and even hands on experience with microfabrication. In addition, academics have done a good job in enhancing essential skills and there are still some categories which need improving but academics should focus on other KSA which are deemed more critical when developing new pedagogical methods to teach advanced manufacturing.

Future results will focus on increasing the number of participants (both industry and academics) in the survey to reduce the deviation. Both content and methods of how to deliver the content are important for engineering education, and this paper describes the content, future studies should investigate the pedagogical methods to deliver the KSA to students. In addition, the paper identified key KSA's that the semiconducting manufacturing industry determined to be necessary for graduate students to have before starting their career in industry.

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