Chapter 7

Workforce Development

The current talent pool and the pathways for creating and supporting a U.S. domestic workforce for microelectronics and advanced packaging technologies (MAPT) fall far short of projected needs for the U.S. While this is part of the pervasive STEM workforce gap in the US, this has reached a critical point with respect to U.S. economic leadership in MAPT R&D, IC design, and manufacturing resulting in considerable national security risks. With the CHIPS and Science Act making $50B investments in the US, the current pipeline for workers across the spectrum of education levels is insufficient by at least an order of magnitude for the next decade across all educational levels. Estimates for the size of the workforce gap for microelectronics and advanced packaging vary. As an example, the Semiconductor Industry Association (SIA) with Oxford Economics estimated in their 2021 Report “Chipping In – The Positive Impact of the Semiconductor Industry on the American Workforce and How Federal Incentives Will Increase Domestic Jobs” [1], that the Incentives funding part of the CHIPS and Science Act will create an additional 89,250 direct jobs and 176,000 supply chain (indirect) jobs in fab operation and 20,000 direct R&D jobs and 18,000 indirect R&D jobs to support the incentive fund investments, not including the additional impact of the CHIPS R&D programs.

In spite of differences between estimates, all agree that the gap is substantial, the pipeline is insufficient and will require focus and time to fill at all levels across the U.S. Several organizations have been studying and mapping workforce development (WFD) including the President’s Council of Advisors on Science and Technology (PCAST), the Department of Defense (DoD), the National Institute of Standards and Technology (NIST), the National Science Board, SEMI, the American Semiconductor Academy (ASA). All studies have converged on the same essential components including pipeline development, inclusion, curriculum development, knowledge, skills, and abilities (KSAs) aligned with critical job functions, access to state-of-the-art education and training facilities and tools for authentic KSA development, experiential learning, and hiring. Recently created teams pursuing CHIPS Act WFD funds are reviewing needs and best practices towards developing strategies for implementing them at scales from national to local and with different target groups. All agree that effective WFD will require combining forces as a national community, leveraging funding to support what has been shown to be effective and what can possibly be effective at the necessary scale.

What differentiates the SRC MAPT WFD Roadmap from other roadmaps is the focus on addressing three specific, critical areas rather than general needs and approaches for MAPT WFD:

- **Quantitative Supply/Demand Modeling** of the needs across all MAPT areas from development to manufacturing including a timeline for when and where employees will be needed with specific KSAs for specific jobs within the industry, rather than aggregate national numbers and generic KSAs, as input to creating models for effective education and training programs.

- **Models for Effective Engagement** to give students career pathways to jobs in MAPT, not simply the list of ingredients for good programs (for example, mentoring, research projects, hands-on, internships, scholarships, teacher training) but also how to combine these for optimal ROI for
the students, the companies, the educational institutions, and other ecosystem members. This will constitute a “Whole of Nation”, and “All Hands on Deck” approach. Note that the term “student” applies to any individual at any stage in their career, including current and recent members of the MAPT workforce and those changing careers.

- **Winning Hearts and Minds** of individuals across the US so they will pursue the educational opportunities that lead to MAPT industry jobs. This includes engaging with K-12 students and teachers to spark an interest in microelectronics and STEM, in general; incentivizing students enrolled in technical education and career programs (vocational programs, community colleges, four-year and graduate programs) to pursue microelectronic careers; and making veterans and displaced workers aware of how their current skills can be repositioned or augmented for the microelectronics industry. This will require not only awareness programs, but also intentional deployment at scale of the most effective models of engagement to reach MAPT WFD goals.

Having jobs available is the first part of the social contract, as captured in section on **Supply/Demand Modeling**. The section on **Models of Effective Engagement** describes how to develop plans to leverage existing, successful programs to address regional and local needs while evaluating new programs which are needed, and which can and cannot effectively be scaled for a national impact. In Figure 1, this spans from core skills starting at middle school at the left through advanced skills gained in a wide range of ways. The current problems in attracting students into MAPT careers are captured in the section on **Winning Hearts and Minds**, as are recommendations for how to apply models of effective engagement at a local-to-national scale to close the gap. There are recommendations throughout and in the conclusions of this chapter to address the MAPT WFD requirements and needs for a robust U.S. semiconductor/microelectronics industry.

This MAPT WFD roadmap cuts across all of the areas and sectors represented in the MAPT Roadmap as individual chapters. This is an interim Roadmap report, with the final version scheduled to be released in October 2023.

Meeting the Microelectronics and Advanced Packaging WFD challenge will require well-developed, effective pathways for students to obtain MAPT jobs in a wide range of technical specialties with a continuous, sustained focus from “the hook” through industry careers. With recruiting, educating, and mentoring students for MAPT jobs, educators and companies are implying a social contract with students for translating KSAs, focused education and training, and a commitment to microelectronics, into meaningful careers in the MAPT ecosystem.

The figure below provided by SEMI illustrates possible career paths that lead to creation of a well-functioning pipeline for MAPT WFD. (Note that SEMI has set quantitative goals for each of these pathways for SEMI-led programs as shown in the left column.) For each of these pathways, sustained outreach and student support are going to be necessary to fill the student pipeline, including, but not limited to, mentoring, research experiences, and internships.
Supply/Demand Modeling

It is difficult to develop WFD action plans and programs given the uncertainty and aggregate nature of the assessments of MAPT WFD needs that currently exist. This is especially true right now, with recent layoffs by prominent companies in the MAPT eco-system. We recommend the development of detailed models and data of the potential MAPT workforce talent pool and KSAs based on company, regional, and national needs as granular as possible. This will serve as a tool to facilitate objective decision-making by policy makers, academic institutions, and industry partners on where to invest to meet specific MAPT WFD needs, and by students on where to direct their futures. These models supported by quantitative data and analysis must necessarily be derived through public/private collaboration. Two important tools that we propose be developed include a Workforce Development Pipeline Model and a KST Matrix.

Workforce Development Pipeline (WFD) Model

The pipeline model will be represented by a diagram with nodes denoting the present population of talent at each stage of education including high school, university, postgraduate study, and employment, with transition points illustrating where the MAPT pipeline shrinks. The model will include transitions from each stage to the next (e.g. annual college graduation rate going to industry or postgraduate study).

Further, this model will be sufficiently detailed to allow analysis of the demographics and geographic location at each stage in the pipeline as this information will be critical in understanding the most impactful ways to stimulate the development of the future semiconductor industry workforce.
To ensure a steady supply of skilled workers, the semiconductor industry has to reinforce the workforce ecosystem through various talent pathways, strengthening talent pipelines and pools, and crossing disciplines as the needed KSAs change over time.

The graph above illustrates the decreasing number of US university undergraduate and graduate students going through the Semiconductor Workforce Development Pipeline in the disciplines of electrical engineering (EE) and electrical and computer engineering (ECE). This was chosen as an iconic example of a leaking MAPT WFD pipeline, given the well-established decrease in students choosing EE and ECE for university degrees. Starting from the left to right, 4.6M students enter high school, with a total of 2.1M, going to college or entering directly into the workforce. There is clearly a massive decrease in students completing STEM to those completing bachelors, masters, or doctoral degrees. As few as 2 thousand highly skilled students eventually pursuing careers in the semiconductor workforce.

**KSA Matrix**

The term Knowledge, Skills and Abilities (KSAs) refers to a combination of qualifications required for a person to perform a specific role with specific tasks. Organizations require several technical and non-technical core competencies to fulfill the roles associated with the semiconductor value chain. These can be classified broadly into R&D, Design, and Manufacturing. Personnel with the required KSAs become integral to key departments such as Engineering, Information Technology, Human Resources, Finance, Legal, Sales and Marketing, Safety & Compliance, and Industrial & Public Relations.

A KSA matrix maps broad job functions to KSAs required to perform specific job functions along with the relative importance of each skill to each job function. By aligning academic milestones to KSAs required for specific job functions and by further aligning curricula, internship, apprenticeship and employment opportunities to the same KSA-based metrics, we believe that it is possible to develop talent pools aligned to job opportunities. Building students’ KSA portfolio can come from a wide range of sources, however, it should be noted that developing a KSA portfolio is often not enough. Students with MAPT
KSA portfolios and meaningful internship and other experiences in industries can develop strong ties with MAPT companies, further leading to career pathways.

As an example, Table 1 is constructed by mapping KSAs to the roles performed in specific jobs requiring EE and ECE backgrounds. A scoring based on needs is performed based on the frequency the KSA is used, and at different levels of expertise. A “K-means” algorithm could be used to perform clustering analysis on the KSA x Role Matrix to identify groups of job functions which in turn can be used in identifying pathways for individuals to obtain such KSAs, and thus in matching individuals to job opportunities. Across the MAPT workforce, some roles may be based on KSAs learned in traditional academic disciplines, such as EE/ECE, materials science and engineering, chemical engineering, civil engineering, and environmental engineering, while others will be based on interdisciplinary or cross-disciplinary KSAs, such as data science, artificial intelligence, machine learning, sustainability, and automation.

Example of Cross-discipline KSA’s– Sustainability:
A resilient workforce with the right knowledge, skills, and abilities (KSAs) will be needed to create a future of energy efficient computing and sustainable technologies, materials, and manufacturing. For all the energy efficiency and sustainability challenges described above, teams of people with combinations of KSAs are needed to solve them. Depending on the specific problem and scope identified above, the disciplines needed will include engineers of all types (automation, chemical, civil, electrical, environmental, industrial, maintenance, manufacturing, materials, mechanical), toxicologists, ecologists, chemists, physicists, mathematicians, statisticians, data scientists, economists, climate scientists, and the list goes on. A key result of the roadmap is the recognition that, for all of these disciplines, sharing a baseline of sustainability knowledge and practice will be critical to solving these problems — to discovering and creating sustainable materials, processes, technologies, and systems. This knowledge must be integrated into disciplinary course work while students are first becoming subject matter experts as undergraduates or else it will never become part of the working level KSAs of the MAPT workforce. The KSAs must then be deepened and put into practice in more advanced courses, MS degrees, research, on-the-job training, and industrial practice. Within multi-disciplinary teams, the gaps, sustainability and otherwise, must be identified and filled to create optimal solutions. At the moment, environmental and EHS impacts are generally an after-thought, considered once the design is set, materials and processes are selected, and end-of-life fate is already engineered.

Other frameworks exist for which linkages have been forged between the KSAs and career opportunities in STEM or more specific subtopics. For example, for more than ten years, the NIST National Institute for Cybersecurity Education (NICE) has been working “to energize, promote, and coordinate a robust community working together to advance an integrated ecosystem of cybersecurity education, training, and workforce development” including developing tools to standardized KSAs for cybersecurity jobs, a supply/demand model for jobs and a mapping of education and training providers (https://www.nist.gov/itl/applied-cybersecurity/nice/resources). Given the magnitude of the MAPT WFD needs in the next 1-5 years, the MAPT community should learn from NICE about what has and has not worked in its partnerships across government, academia, and the private sector, with a focus on accelerate the pace of MAPT WFD.
Table 1: Conceptual diagram relating KSAs and the frequency of use in MAPT jobs

<table>
<thead>
<tr>
<th>Role</th>
<th>Data Analysis</th>
<th>Statistics &amp; DOE</th>
<th>Coding/Programming/Shell Scripting</th>
<th>ML</th>
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<tbody>
<tr>
<td>Design Engineer</td>
<td>Level 1</td>
<td>Level 1</td>
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<tr>
<td>Engineer/Security/Arch</td>
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<td>Process Engineer</td>
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<td>Metrology</td>
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<td>Equipment Engineer</td>
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<td>Process Control</td>
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<td>Packaging Engineer</td>
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<td>Integrators</td>
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<td>Yield and Reliability</td>
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<td>Engineer</td>
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<tr>
<td>Software Engineer/Developer</td>
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<td>Environmental Engineer</td>
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<tr>
<td>Fab / Lab Technician</td>
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<tr>
<td>Field Service Engineers</td>
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<tr>
<td>Program Managers</td>
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<td>Supply Chain Manager</td>
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<tr>
<td>HR</td>
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- **Skills Expertise**
- KSA mapping of skills to job function
- Clustering analysis allows grouping of job functions

**Example of k-means clustering of roles**
Recommendations

- Develop quantitative supply/demand modeling for MAPT WFD from development to manufacturing including a timeline for when and where employees will be needed with models integrated with specific KSAs for specific jobs within the industry and linked to education and training program outcomes.
  - Validate the model against new data periodically to update/correct
  - Validate the model with industry needs and gaps
  - Develop community (govt, industry, academia) driving model use and impact
- Update the KSAs for the evolution of job requirements, including but not limited to AI, machine learning, sustainability, and automation.
  - Analyzed the matrix for gaps and common trends to leverage for engagement models
  - Prioritize areas of need
  - Update/maintain the matrix based on changing needs and roles over time

Assuming that high fidelity supply/demand models and KSAs are developed to identify MAPT jobs now and in the future, how are these to be used? The following two sections of the roadmap address the questions:

- How can the KSA gap be filled for existing (and future) students in a way that produces motivated, industry-ready students?
- How can the number of students in the MAPT pipeline be increased by “winning students’ hearts and minds”?

Effective Models for Engagement

Identifying needs and gaps through effective modeling provides guidance towards areas of focus to engage students with effective programs. There is a need to engage students and the transitioning workforce to consider careers in STEM fields, and particularly the MAPT industry, and to do so in a way that builds and sustains a broad and diverse talent pipeline to meet the workforce needs. There are many existing engagement models and programs across the country to leverage but also a need to identify new methods. The engagement models should focus on the 5 following areas listed below and with further details following the list:

1) **Awareness**: Widen the pipeline by increasing overall industry, career, and employer awareness for U.S. students, teachers, professors, counselors and parents; veterans; women; underrepresented people of color; and rural residents
2) **Building communities/pipelines**: Develop sustainable, effective engagement opportunities for industry employees that connect them to K-12, community colleges, Univ teachers / professors / students
3) **Diverse talent**: Reach diverse talent pipelines by linking programs from high schools, vocational schools, and community colleges with a focus on underserved, tribal, and rural student populations and those transitioning from other industries.
4) **Industry Practice**: Change industry practices to help them recruit, hire, retain, and promote a more diverse workforce
5) **Scale for impact:** Scale effective programs and models including mentorship, apprenticeship, internships, curriculum alignment by understanding and quantifying the ROI for different effective models so that investment choices and commitments can be made by different stakeholders.

**Awareness:** Building industry, career, and employer awareness with a more diverse range of students and adults is a key workforce priority for the industry. It is imperative to address not just awareness of the industry, but also its image, to compete with adjacent industries that are vying for the same talent. Multiple programs, activities, and channels are needed to reach K-12 and university/college students, older adults needing to re-skill or up-skill, veterans, women returning to work, and more. Examples of some potential programs which can be scaled include:

- **Industry Image and Awareness Campaign** – a series of national and regional media activities that highlight the industry.
- **SEMI High Tech U and related initiatives** – programs that encourage industry employee engagement in classrooms, teacher training, tools to help families understand the industry, its companies, and its wide range of career opportunities.

**Building communities/pipelines:** Community engagement between industry, schools, and communities is a powerful way to interest students and adults in MAPT careers, particularly by introducing them to working professionals who can share stories about their personal careers and education pathways. These professionals can bring practical real-world applications, challenges, experiments, and activities into classrooms, and can lead internship, apprenticeship, coaching and mentoring programs in the communities. One of the priorities should be to develop a series of ongoing engagement opportunities for industry employees, teachers, counselors and students. Examples include:

- **A Career Ambassador Program** that companies can participate in which provides the training, tools, and interaction opportunities for industry employees to lead classroom discussions.
- **Leverage existing work-based learning experiences** that can be replicated across other companies nationwide, for example [Micron Foundation’s Job Shadow](https://micronfoundation.com/job-shadow) and [Chip Camp](https://www.chipcamp.org) programs for high school students that provide virtual and in-person immersions.
- **Support of Heroes Connect webinars** organized by Heroes MAKE America highlight semiconductor companies and career opportunities to transitioning service members and veterans.
- **Industry led awareness programs** prepare communities where semiconductor industry has not had a large footprint such as Semiconductor Day at Ohio State and a women-focused event at University of Cincinnati.

**Creating Diverse Talent Pipelines:** A focus on underserved, tribal, and rural student populations will grow the overall size of the semiconductor talent pool. Programs need to be prioritized and customized for underserved, tribal, and rural student populations. Talent diversity programs should also be combined with longer-term investments and commitments in these communities to fully support students’ needs in other areas that contribute to overall success.

To ensure we capture the widest possible pool of talent, these stronger linkages will be forged between high schools, career and technical education schools, military training programs, community colleges, and 4-year universities, and will rely on strong industry engagement and support.

Examples of required effort include:
● Gathering data to identify these schools across the nation, examining existing programs, adopting best practices, and finding key local contacts to start the collaboration process state-by-state.
● Aligning high school courses and content with community college certificates and programs.
● Expanding dual credit programs and investigating course credits for conducting research with university faculty and identifying more transferable credit courses.
● Expanding traditional community college programs into more semiconductor-aligned areas,
● Partnering with professional teacher associations (e.g. NSTA, CSTA) to advocate for more STEM teacher investments and incentives to recruit more diverse groups into the profession.
● Incentivizing access through industry-sponsored university scholarships

**Improving Industry Diversity Practices:** In the last 12 months, there were more than 84,000 job openings reported by SEMI member companies with an estimated additional 70K to 90K MAPT jobs expected in the coming 3 years, particularly with new fabs coming on line. The industry cannot afford to exclude any potential talent. Women hold only 25% of computing-related jobs (with just 3% of those jobs held by Black women). Women are only 14% of our engineering workforce and only 22% of C-Suite leaders are women. Black people comprise less than 5% of the tech workforce. Latino people make up 7%. Furthermore, there are zero Black CEO’s among Fortune 500 tech companies and 83% of tech executives are white.

These inequities result in decreased innovation, productivity, competitiveness, and profitability. With the U.S. shifting toward a more ethnically and culturally diverse population, the semiconductor industry must attract more diverse talent to address current and future workforce shortages and reach its full potential.

Industry and education need multiple strategies to address these systemic problems including addressing bias in company cultures, framing job opportunities to be more welcoming to a diverse array of candidates, representing women and people of color in their marketing and communications, and leadership development and promotion practices, to ensure that women and people of color have clear pathways to advancement. Tools and support available to companies include:

○ SEMI organization’s Roadmap to Diversity, Equity, and Inclusion, and DEI Toolkit which support industry to improve diversity.
○ Webinars, training, and research on DEI.
○ Mentoring programs for industry women and people of color to create 1-on-1 bonds with women and people of color in Grades 7-12, illustrating, “I can do it too!”
○ Annual ‘Women in Semiconductors’ program led by industry professionals focuses on strategies for women to succeed in semiconductor manufacturing, including leadership strategies.

**Scaling Effective Engagement Initiative for Impact:** There are many existing initiatives focused on increasing engagement of students and older adults to pursue careers in the semiconductor industry, but many of the programs lack the reach required to make an impact on the workforce demand. What is needed is a way to broaden the impact of those programs by more-seamlessly connecting the demand (the semiconductor companies) with the supply (the talent pool and educational institutions). We propose the establishment of a global, on-line, open-source platform that can serve as an aggregated resource bringing together students, employers (the MAPT industry), professional societies, industry groups, educators (K-12, community colleges, and 4-yr colleges/universities) and workforce training providers. Through early and large-scale adoption of the MAPT industry and industry groups (e.g. SEMI,
SRC, SIA) this platform would be well-positioned to attract existing large-scale repositories of career guidance resources, MAPT curriculum content, internship, coop, and apprenticeship opportunities, virtual and on-line training resources, and relevant certificate-based programs. For key MAPT workforce development resources where existing repositories are lacking it is recommended that such repositories be established and incorporated within this portal. With sufficient participation by the MAPT industry, industry organizations and key national/regional MAPT WFD organizations (e.g. NSF, US DOL, NIIT, etc...) such a portal could serve as a primary entryway to pursue semiconductor careers for students and the transitioning workforce. This would allow these talent pools to learn about the industry and would provide resources – either directly or through partner organizations – for training and development. It will reduce barriers to engagement, support sharing of best practices among industry and educators, and facilitate crucial connections to build the workforce of the future.

Web-analytics of the portal will provide valuable information on the effectiveness of specific programs to reach the target audiences and drive the development of new initiatives and content. Government support to fund the development of open-source content will be critically important, as well as on-going support to build, expand, maintain, and curate the site.

**Recommendations.**

- Establish and curate a global, on-line, open-source platform where semiconductor companies, professional societies and industry groups, universities and community colleges, K-12 educators can develop and post career guidance resources, curriculum content, internship, co-op, and apprenticeship opportunities, virtual and on-line training, and certificate programs.
• Create incentives for collaboration and require clear metrics to show and improve effectiveness
• Add new program content or updates to existing content as needed so that the site remains current.
• Use web analytics to measure the effectiveness of portal content to support the workforce objectives.
• Provide sustained government funding for the development of open-source content, as well as on-going support to build, expand, maintain, and curate the site.

**Winning Hearts and Minds**

Meeting the workforce needs of the U.S. MAPT industry requires developing a system that will attract and support a sufficient number of students who are interested in pursuing the education and training necessary to qualify for jobs in the industry. Students make a series of decisions, even as early as elementary school, about career path decisions whether they recognize the significance of those decisions at the time or not. For example, the level of middle school mathematics to which a student is assigned can determine whether or not the student can pursue a 4-year undergraduate STEM degree. Many factors can influence these transition points and decisions, and there are significant factors and combinations of factors that lead students to leave the STEM and MAPT pipelines. Creating workforce development programs for STEM and MAPT is predicated on the belief that effective strategies can be identified to change students’ decisions, recognizing that what has worked in the past is not working now at the scale necessary and will likely not work any better in the future.

**MAPT WFD: A Special Subset of Issues with STEM Education**

The development of core skills needed to participate in the semiconductor workforce and other STEM careers begins in middle school and continues throughout high school. The Nation’s strategic plan for STEM education, *Charting a Course for Success: America’s Strategy for STEM Education*, published in December 2018, urges increased collaboration among learners, families, educators, communities, and employers to achieve three overarching goals: building a strong foundation for STEM literacy; increasing diversity, equity, and inclusion in STEM, and preparing the STEM workforce for the future.

The plan encourages the formation of STEM Education Ecosystems and provides the following definition: STEM education ecosystems consist of multi-sector partners united by a collective vision of supporting participation in STEM through the creation of accessible, inclusive STEM learning opportunities spanning all education stages and career pathways. A STEM education ecosystem continuously evaluates its activities and adapts as needed, plans for the long term, and communicates its work to build broad support and advance best-practices.

The plan recommends that educators engage students where disciplines converge to make STEM education more meaningful and inspiring. There is an ongoing evolution of K-12 STEM education from siloed discipline-specific activities to a more integrated approach which offers excellent opportunities for introducing K-12 students to semiconductors and microelectronics and is nearly absent from existing STEM activities. Activities that highlight the connection of technology to solving complex real-world problems with social or personal implications are thought to be particularly effective in broadening participation in STEM.
The extent to which academic instruction can be augmented by Career and Technical Education (CTE) in middle school and high school varies from state to state. *Advance CTE*, a non-profit organization that represents state directors and leaders of CTE, provides access to a plethora of online resources for designing, assessing, and marketing CTE programs ([www.careertech.org](http://www.careertech.org)) to students and their families. Industry engagement is critical to developing meaningful CTE experiences and helping students understand how their studies can lead to job opportunities at all levels.

Regardless of access to CTE, students will be urged to begin exploring career options prior to graduation. Decisions will be influenced by teachers, school counselors, family, and friends, which speaks to the need for STEM ecosystems which highlight microelectronics and engage individuals both within and outside the formal education system. Museums, libraries, after-school programs, and community groups can play an important role in sparking interest in STEM and forming opinions about STEM career paths. Social media, internet resources, and other virtual environments can provide opportunities to reach students who may not have access to quality in-person experiences.

Currently missing from our understanding of how students make choices away or toward MAPT careers is hearing the voices of today’s students. Past surveys of college graduates have produced results that led to both deep understanding of the factors that affect students’ college experiences and what action can be taken to improve them. For example, the 2015 Gallup-USA Funds Minority College Graduates Report, based on the Gallup-Purdue Index studies, that black HBCU graduates were more likely to strongly agree than black graduates of other institutions that (1) their colleges prepared them for life after graduation, (2) they had a professor who cared about them as a person, (3) they had a professor who made them excited about learning, and (4) they had a mentor who encouraged them to pursue their goals and dreams, with the largest gap being for having a professor who cared about them as people (58% vs. 25%). In the more recent Gallup Alumni survey “college graduates are almost 2X more likely to be engaged at work if they had a mentor who encouraged them to pursue their goals and dreams.” and “graduates are 1.4 times more likely to be thriving in five key elements of well-being if a professor cared about them as a person.” Having current, in-depth results for different universities and colleges and from students with different backgrounds in the context of STEM and MAPT education, training, and careers could be invaluable in making the right choices and investments for increasing the effectiveness of MAPT WFD programs.

**Recommendations:**

- Support the Nation’s Strategic Plan for STEM Education by building and supporting regional STEM ecosystems which include microelectronics awareness and that bring together learners, families, educators, communities, and employers. Ensure microelectronic/semiconductor awareness and impact is addressed in this program.
- Engage individuals who are knowledgeable about age-appropriate and culturally-sensitive pedagogy with practitioners in the semiconductor field to develop learning experiences that can be delivered in both formal and informal settings.
- Ensure that the global, online, open-source platform recommended above is effective at “winning students hearts and minds” at a wide range of education levels, geographical locations, and demographics and have mechanisms and incentives for students, teachers, industry, and other to use and share materials on the platform for attract and retain student interest.
- Develop and provide training programs for middle and high school teachers that show how examples and activities featuring semiconductors can be incorporated into the curriculum.
● Develop and deliver authentic career exploration programs (summer camps, shadowing experiences, career and technical training programs, and summer employment)
● Provide students with opportunities to earn high school and college credit while learning about the semiconductor and advanced packaging industry
● Develop and deliver national image and awareness campaigns to introduce high school students and influencers (teachers, school counselors, and family members) to jobs in the semiconductor industry
● Create a marketing and branding tool kit that can be readily adapted by different members of the ecosystem for different audiences and programs.
● Conduct a new “Gallup” survey to identify the most important factors in student success and in having students choose or not choose STEM and MAPT as career paths, with the goal of identifying where action can make the most difference.

Area of Immediate Need: Post-Secondary Career and Technical Education

Post-secondary Career and Technical Education (CTE) is important for training technicians for the MAPT industry. The CTE programs offered in a given region often depend on local workforce needs, but the content of these programs is also informed by the CTE National Career Clusters Framework. Developed to guide curriculum design and instruction, the framework maps 79 career paths within sixteen career clusters, including STEM, Manufacturing, and Information Technology which are particularly relevant to the semiconductor industry. Efforts are underway to modernize the framework with input from a variety of stakeholders, and this may provide the industry with an opportunity to ensure that future CTE offerings are well aligned with the industry KSAs.

Recommendations:

● Work with local and regional CTE providers to shape the post-secondary programs available to students.
● Map current CTE competencies to desired MAPT KSAs
● Engage with local and regional CTE providers to support their recruiting efforts and to develop industry-specific content that compliments existing programs.
● Provide scholarships to incentivize students to complete industry-specific training.

College Pipeline

A student who chooses to enroll in a STEM discipline in a community college or university is well on their way along a career path that could lead to employment in the MAPT industries. However, as highlighted earlier, a significant percentage of students entering STEM disciplines drop out in the first few years. Thus, we cannot assume those entering will make it through to industry hires. There are a plethora of factors that contribute to students switching majors or even leaving higher education altogether. For some students, it is simply a matter of economics and family commitments; they simply cannot afford to continue their studies. Others conclude that a STEM career is not for them, often based on misconceptions about future careers, and on the lack of a supportive community. Financial incentives and exposure to experiences that reinforce that STEM careers can make a difference in the world, foster a sense of belonging, and lead to rewarding careers are all effective ways to reduce leaks in the MAPT pipeline.
Only a few academic programs in the U.S. focus specifically on semiconductor science and microelectronic engineering, and most of these are graduate programs for master’s and doctoral students. As noted above, enrollment in EE/ECE, which is especially important to the MAPT industry, has been declining over the past decade. Meeting the workforce demands of the MAPT industry requires expertise from many disciplines, yet few students enrolled in these majors will get significant exposure to their field during their studies.

**Recommendations:**
- Incentive interest in the semiconductor industry by providing work-based learning (WBL) opportunities, such as scholarships, internships/coop, apprenticeships, fellowships, and other forms of experiential learning
- Support professional student clubs and sponsor competitions to encourage extracurricular interests aligned with the industry needs
- Programs with examples of microelectronics impact to the environment and society - now and in the future - to build “Change the World” awareness and motivation.

**Military Service Pipeline**
There are additional sources of potential talent to feed into the semiconductor industry such as military veterans. Many are not aware of how their military experience can be applied towards employment in microelectronics. Providing information and job opportunities to those leaving the military as well as necessary training to build the necessary KSAs can add to the potential workforce. In addition to the education path to develop awareness and talent for the semiconductor industry.

**Recommendations:**
- Develop an awareness program for military veterans which highlights microelectronics job opportunities and training resources
- Develop a “map” of military experience abilities which are applicable to the semiconductor industry - all levels.
- Ensure there are appropriate training programs to transition from military to semiconductor jobs and placement services
- Understand the constraints and barriers to military veterans pursuing these job opportunities and training programs

**Diversity, Equity, and Inclusion**
Key to any successful enterprise is diversity of thought, perspective and ideas which requires a diverse employee population. Achieving such a population requires both awareness and access for all from underserved /underrepresented gender, nationality and social/economic environments

**Recommendations:**
- Develop a national awareness and information program to reach a diverse population – much of which may not be aware of the MAPT opportunities available to them
- Work with industry to be equitable in hiring.
Concluding Remarks: Semiconductor Workforce is a Holistic Effort

The preceding discussion highlights the many facets of workforce development which are required to meet the increasing demands of the microelectronics industry. We addressed three areas:

- Accurate Supply/Demand Modeling
- Models for effective engagement
- Winning hearts and minds

All three are required to build and maintain an effective workforce necessary for the expanding U.S. MAPT industry.

- We need an effective model including KSAs, timelines, numbers, pathways specific to national and regional areas and to different demographics to best plan for the workforce needs. Without such a model as highlighted earlier, we would be “shooting in the dark” as to where and when to target workforce with the needed KSAs which will also change with the evolution of the industry.
- Effective engagement methods need to be identified along with a cost/impact estimation (leveraging the supply/demand model) which can be scaled for significant impact. There are already many very good examples in pockets across the U.S. which should continue, but many are not scalable to have nationwide industry impact as needed for the future. We need to continue to analyze these and identify gaps/opportunities to improve in order to meet demand.
- Winning the Hearts and Minds of students and prospective future employees requires building the awareness, excitement and global impact of the semiconductor industry. Increasingly, students are interested in careers which can “change the world” and are impacted by what they hear, see and experience starting at a young age. Thus, we need to build the awareness and excitement starting with STEM education but going “beyond” existing programs to add more emphasis on microelectronics and semiconductors.

The time to start is now!

Following is a draft timeline summary:

<table>
<thead>
<tr>
<th>Key WFD Focus</th>
<th>1 year</th>
<th>3 years</th>
<th>5 years</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply/Demand Modeling</strong></td>
<td>- Develop community (driving use of supply/demand pipeline model and KSA framework to accelerate MAPT WFD. - Industry aligned and validated MAPT KSAs for specific job types linked - Set priority list for validated data collection over time - Conduct initial impact scenario analysis</td>
<td>- Mapping KSAs and jobs to local, regional, and national education and training needs/jobs - Adjust models to incorporate workflow changes as a result of automation, AI, business models, supply chain development - Validate supply/demand modeling, KSA matrix, links to education and training has impact using metrics</td>
<td>- Update Mapping of KSAs and jobs to regional needs - Update models to incorporate workflow changes based on needs and methodologies. - Validate supply/demand modeling, KSA matrix, links to education and training has impact using metrics</td>
<td>- Update Mapping of KSAs and jobs to regional needs - Update models to incorporate workflow changes based on needs and methodologies. - Validate supply/demand modeling, KSA matrix, links to education and training has impact using metrics</td>
</tr>
<tr>
<td>Winning Hearts and Minds</td>
<td>Effective Engagement</td>
<td></td>
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</tbody>
</table>
| - Defined awareness program K-12 – beyond STEM targeted in areas with CHIPS Incentive Funding  
- Develop plan driving the “whole of nation” approach, including underrepresented groups, HBCUs & MSIs, CCs, colleges  
- MAPT Impact – “change the world” campaign initiated.  
- Gallup survey designed and funded  
- 20% increase in engineering for MAPT college admissions across a broad education and training ecosystem  
- Results from Gallup survey incorporated into MAPT “winning hearts and minds” strategies and WFD programs. | - Existing programs evaluated for metrics effectiveness and prioritized for scaling.  
- Gaps in existing programs determined with industry engaged in filling the gaps.  
- Clear metrics for success defined for WFD programs and investment  
- Industry supported mentorships, scholarships, apprenticeships, internships in place  
- Goals, metrics, and organization defined for online, open-source education and training platform.  
- Develop design and assessment framework, and operational process for online, open-source platform.  
- Incorporated Industry, community colleges, universities, and non-profits for content  
- Identify approaches to mentoring, community support, | - Selected programs operational  
- New programs developed and pilots in evaluation, Industry engaged in K-12 awareness to meet the U.S. workforce needs  
- Results-driven strategies developed and tested to increase the number of individuals prepared to work in the MAPT  
- Assess the scaling effectiveness of programs for MAPT education and training platform  
- Communication/marketing plan established and underway.  
- MAPT education and training platform on-line covering: Industry awareness and promotional material; Mentorships, scholarships and internships; Open source K-12 materials; On-line certificate programs; Apprenticeships & earn-and-learn programs; Teacher  
- On-going assessment of platform effectiveness with New content and technologies added as they become available including updated existing content | - 50% increase in engineering for MAPT college admissions  
- On-going assessment of platform effectiveness with New content and technologies added as they become available including updated existing content | - 100% increase in engineering for MAPT college admissions  
- On-going assessment of platform effectiveness with New content and technologies added as they become available including updated existing content |
other services to introduce and retain students in the pipeline - Web analytics used to monitor effectiveness of the platform.

- training and best-practice sharing.

- Web analytics used to monitor effectiveness of components of the platform.

This is an interim workforce roadmap report and, as such, the recommendations are preliminary but do identify key areas of focus and development for the final report.

Appendix:

Winning Hearts and Minds Resources:

STEM Ecosystem

ERIC - ED590474 - Charting a Course for Success: America's Strategy for STEM Education. A Report by the Committee on STEM Education of the National Science & Technology Council, Executive Office of the President, 2018-Dec

STEMM Opportunity Alliance

FACT SHEET: Biden Harris Administration Announces Bold Multi-Sector Actions to Eliminate Systemic Barriers in STEMM | OSTP | The White House

Broadening Participation in STEM

Encouraging Girls in Math and Science Encouraging Girls in Math and Science (ed.gov)

Broadening Participation in STEM | CADRE (cadrek12.org)

Career and Technical Education

What we know about Career and Technical Education in high school (brookings.edu)

Advanced CTE Website Home | Advance CTE (careertech.org)

Veterans

NSF 101: Expanding pathways to STEM careers for veterans | NSF - National Science Foundation