Mechatronics
A Technology Forecast

Implications for Community & Technical Colleges in the State of Texas

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Mechatronics

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TEXAS STATE TECHNICAL COLLEGE SYSTEM
About the cover

The toys our children play with are for more than just entertainment. When children play, they can express natural abilities that grow into talents and shape their future career interests. Robotics represents the essential elements of mechatronic systems, the same systems found in modern jet engines, wind turbines and even the common automobile. The robot depicted is Qwerk from Charledlabs.com. Special thanks to L3 in Waco, Texas. Photograph by Mark Burdine, Texas State Technical College Waco.

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Acknowledgments

Any reasonably comprehensive forecast is founded on the efforts of a number of individuals, including a number of recognized experts. In a technical area such as mechatronics, in which there are few referents and little common ground across industries, the most productive means for gathering relevant, accurate and timely information is to go directly to the people involved in various aspects of its application on a daily basis.

As such, one of the most productive activities in developing this forecast was a series of interviews the authors conducted with employers and the program directors of existing mechatronics programs in the United States. The value of these interviews is founded on the knowledge, experience and insight of the participants from both industry and training programs at the community and technical college level. The authors sincerely appreciate these experts taking the time to participate in the interviews. Educational participants include:

- Dr. Ken Ryan, Director, Center for Automation and Motion Control, Alexandria Technical College.

- Michael Halbern, Director, Mechatronics Program, Sierra College.

- Stephanie Guevara, Dean, Business and Technology Division, Sierra College.

- Dr. Ronald McMurtry, Director of K-12 Partnerships and Professor of Electrical Technology, West Kentucky Community College.

- Pat Hobbs, Vice President of Student Learning, Texas State Technical College Harlingen.

- Sam Nauman, Director of Advanced Manufacturing Integrated Systems Technology Laboratory, Texas State Technical College Harlingen.

Listed in Appendix B, “Experts Consulted,” are the names of 10 other experts who were consulted by the authors during the development of this forecast. Each of these experts provided information, opinions and insights that were of major value and we would like to thank each of them for their courtesy, patience and willingness to contribute to the project.

The authors would also like to sincerely thank the 41 representatives of various companies that took the time to respond to our survey. The survey and a list of organizations that took part in it are listed in Appendix A.
The authors would also like to express their appreciation to Debra Robison, Sam Nauman, Mark Long and Eliska Flores for their efforts in editing and formatting this report, and Mark Burdine for the cover photography. Finally, the authors would like to thank the staff at Texas State Technical College Publishing for preparing the report for final publication.

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Preface

The Texas State Technical College System (TSTC) Emerging Technologies contracted with Technology Futures, Inc. (TFI), VentureRamp, Inc. and independent consultants to conduct an analysis and provide conclusions and recommendations that curriculum decision makers throughout the state could use to make strategic and informed decisions regarding the development of new and/or updating existing educational programs related to workforce needs in the area of mechatronics.

This report presents the results of that analysis in the sincere hope that the Texas Higher Education Coordinating Board (THECB) and community and technical colleges (colleges) throughout the state can use to inform planning and decisions related to the Texas workforce and its educational pipeline and institutions which serve the economic and developmental capacity of human capital in the state of Texas.

Scope

The term “mechatronics” encompasses a broad range of technical disciplines including mechanics, electronics, control systems and computer systems. As a result of this breadth, the term has number of different meanings to different people. In this report, the term “mechatronics” is defined in the broadest sense. That is, mechatronics is defined as the multidisciplinary application of mechanics, electronics, control systems and computer systems to optimize the performance of products or processes.

As products and systems have become increasingly mechatronic, it has become necessary that the people who design, install, maintain, repair and calibrate this equipment have skills which integrate mechanical, electronic and software systems. In many industries, equipment and systems technicians are already mechatronics technicians who have developed multidisciplinary skills over the past 10-20 years. Thus, the concept of a mechatronic technician is not new, but the idea of formalizing this type of training into degree programs is fairly recent, at least in the United States. In fact, the term mechatronic is foreign in the US, but common in European and Asian industry and in schools. In the US, the closest term the authors found in industry is “Multi-craft.” Multi-craft technicians are mechatronic technicians and therefore, the terms “mechatronic” and “multi-craft” are used interchangeably throughout this report.

Report Organization

Chapter One presents a series of observations about mechatronics, its implications for colleges, an explanation of the methodologies used in the project and a series of recommendations. Chapter Two presents information and insights related to mechatronics and its impact on various industries. Chapter Three addresses employment opportunities for graduates of college programs in the area of mechatronics, including current and future demand for mechatronics technicians,
probable salaries and required knowledge, skills and abilities. Chapter Four presents information and suggestions that will be of value to college decision makers in considering whether to initiate mechatronic programs and, if so, how this can best be accomplished. The chapter includes information on best practices regarding the development of mechatronic programs in addition to information concerning the cost of initiating such programs and securing properly trained faculty.

Chapter Five presents information concerning industry and education partnerships that colleges can leverage to develop their own mechatronic curricula. The chapter also includes information and insights from the directors of existing mechatronic programs in other states, including California, Kentucky and Minnesota, that might be useful to colleges in the development of mechatronic programs. Chapter Six presents conclusions drawn by the authors regarding the importance of mechatronics to the state of Texas in general and the state’s colleges, in particular. Appendix D provides a directory of companies that utilize mechatronics in the production of manufactured goods and/or the provision of services. This list, which includes contact information for individuals within those companies who are responsible for hiring mechatronics technicians, will be especially useful to college decision makers that are trying to assess the need for mechatronic programs in their region and also in the development of local advisory committees. Finally, Appendix E provides summaries of select mechatronics-related K-12 programs in areas such as competitive robotics.
Executive Summary

Mechatronics is a system of technologies which integrates mechanical and electrical systems through control systems and information technology. Mechatronics is another way of saying “intelligent mechanical systems.”

The National Council on Competitiveness estimates that 100 million new jobs will be created in the 21st century at the intersection of disciplines rather than in individual disciplines. Mechatronics technicians exhibit this multi-disciplinary or multi-craft requirement today and are in high demand across all of Governor Perry’s targeted high growth industries.

There is no mechatronics industry sector; rather, it is an enabling approach to technology that is increasingly applied in a number of economic sectors including: Biotechnology, Life Science & Medical; Electronics & Applied Computer Equipment; Telecommunications & Information Services; Distribution, Transportation & Logistics; Heavy & Special Trade Construction; Energy, Mining & Related Support Services; Petroleum Refining & Chemical; Transportation Equipment; Production Support & Industrial Machinery; Agriculture, Forestry & Food; Aerospace, Homeland Security and Defense.

Mechatronics is at the heart of systems such as cochlear ear implants for the hearing impaired and anti-lock breaks in automobiles. Mechatronics is an enabling manufacturing technology for traditional industries and also a foundational manufacturing technology for micro-to-nano scale manufacturing.

Exhibit ES.1. Mechatronics Applications
The number and type of systems that can be fairly considered mechatronics are broad and span many industry sectors. These systems include everything from the household clothes dryer that uses a moisture sensor to turn itself off when a load of clothes is dry to a complex, highly-automated wafer stepper that produces integrated circuits in a thousand step semiconductor manufacturing environment. Other representative mechatronic systems include “household name” items such as hard disk drives, ATM machines, anti-lock braking systems for automobiles and even casino slot machines.

As mechatronic products and processes have become more pervasive, it has become increasingly necessary that employees working in technologically advanced environments be competent in the multidisciplinary application of the various technologies associated with mechatronics. Industry refers to this multidisciplinary as “multi-craft.” To industry, multi-craft is the ability to integrate many traditionally separate specialized work functions into one person who is multi-skilled. The potential impact of this integration is skill mergers and job mergers. Skill mergers integrate skills across job functions and job mergers integrate jobs replacing two or more workers with a single worker with multi-craft abilities. Skill mergers and job mergers are themes that should be tracked through further research as their impact over the next three-to-ten years may be significant and related to the evolution of technologies and work environments.

Mechatronic technicians may be systems operators, technicians or engineers. Incumbent workers who have developed multi-craft mechatronic skills have achieved competency in mechatronics through on-the-job experience or company training. There are very few college programs in Texas graduating students with multi-craft Knowledge, Skills and Abilities (KSAs). Texas employers that we surveyed and interviewed, however, see significant value in formal mechatronics training and work applicants. Several community and technical colleges (colleges) in the United States, including Texas State Technical College Harlingen, have recognized the need for mechatronics training and have constructed mechatronics curricula to prepare technicians with multi-craft skills and knowledge.

**Mechatronics as a Career**

The job title “mechatronic technician” is not widely recognized; however, some industries that require mechatronics technicians use the term “multi-craft.” There is not a mechatronic technician or a multi-craft standard occupational code. Students who graduate from mechatronic programs fill positions with existing occupational titles such as electromechanical technician, process technician and semiconductor technician. Therefore, it is not possible to make exact projections about the demand for mechatronic technicians from standard labor market information data.

To gather timely information concerning the employment opportunities for mechatronic technicians, Technology Futures, Inc. (TFI) and the Texas State Technical College (TSTC) Emerging Technologies conducted a survey of potential Texas employers.
Greater than 60 percent of survey respondents agree that in order to maintain competency, most technicians have had to acquire mechatronic skills through On-the-Job-Training (OJT).

**Exhibit ES.2.** Survey Question: Most Technicians Hired in Recent Years Have Had to Become Mechatronics Technicians, Typically through On-The-Job Training, in Order to Maintain Job Competency

The increasing importance of mechatronic multi-craft KSAs is particularly evident in the way employers view the evolution of related labor markets. Exhibit ES.4 illustrates that although about half the survey respondents had no opinion with respect to the impact of increased mechatronic employment on related fields, those respondents who did have a position clearly see mechatronics as an additional required skill set in addition to traditional technical fields.

**Demand**

Employers see significant value in people with formal mechatronic training. According to 80 percent of survey respondents, mechatronics training can decrease the cost and time needed to train technicians in the required skills and it minimizes the risk of hiring employees who do not have the ability or desire for multidisciplinary training. Nearly 80 percent of survey respondents indicated that formal training would reduce the time to acquire skills to be a productive mechatronic technician.
Exhibit ES.3. Survey Question: Formal Mechatronics Training Can Materially Decrease the Time Necessary to Gain the Skills Required for Successful Mechatronics Employment

The need for technicians broadly and holistically trained in mechatronics appears to be widespread. Directors of mechatronic programs in California, Kentucky and Minnesota indicate that graduates of their programs and other comparable multidisciplinary programs, such as robotics and advanced manufacturing, have almost all been hired on or even before graduation.

Eighty percent of survey respondents indicated they would hire at least one mechatronics-related technician within the next one to three years and 70 percent would hire at least one in the next year. By the most conservative estimate the 41 respondent companies alone will require 230 mechatronic technicians in the next 12 months and will require over 400 mechatronic technicians in the next one to three years. Five respondent companies indicated that they would hire at least 50 mechatronics-related technicians in the next three years. Three of these companies were large semiconductor manufacturers.

Exhibit ES.4. Survey Question: Anticipated New Mechatronics Hires in the Next 12 Months

<table>
<thead>
<tr>
<th>Number of New Hires in Next 12 Months</th>
<th>Respondents</th>
<th>Percent of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>10</td>
<td>26%</td>
</tr>
<tr>
<td>1–3</td>
<td>14</td>
<td>36%</td>
</tr>
<tr>
<td>4–6</td>
<td>7</td>
<td>18%</td>
</tr>
<tr>
<td>7–15</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>16–25</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>26–50</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>More than 50</td>
<td>3</td>
<td>8%</td>
</tr>
</tbody>
</table>

Number of respondents: 39
Exhibit ES.5. Survey Question: Anticipated New Mechatronics Hires in the Next One to Three Years

<table>
<thead>
<tr>
<th>Number of New Hires in Next 1-3 Years</th>
<th>Respondents</th>
<th>Percent of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>7</td>
<td>18%</td>
</tr>
<tr>
<td>1–3</td>
<td>11</td>
<td>28%</td>
</tr>
<tr>
<td>4–6</td>
<td>8</td>
<td>21%</td>
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<td>7–15</td>
<td>2</td>
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<tr>
<td>16–25</td>
<td>5</td>
<td>13%</td>
</tr>
<tr>
<td>26–50</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>More than 50</td>
<td>5</td>
<td>13%</td>
</tr>
</tbody>
</table>

Number of respondents 39 100%

Estimated Salary Levels

Seventy-three percent of survey respondents indicated that the entry-level starting salary for mechatronics-related technicians would be in the $30,000 to $45,000 range. Sixty-one percent indicated that the salary would be in excess of $45,000 for employees with five years of experience and none reported average salaries less than $30,000. According to the survey data, the average entry-level mechatronic technician salary is $34,230 and average salary after five years is $47,727, which amounts to a nearly 7 percent increase in pay per year.

Exhibit ES.6. Survey Question: Average Mechatronic Technician Entry-Level Starting Salary

- 6% for $20,000
- 12% for $25,000
- 39% for $30,000
- 33% for $35,000
- 9% for $45,000
- More than $55,000
**Size and Location of Markets**

Analysis of data obtained from the Texas Workforce Commission Occupational Employment Statistics Program, 2005, which tracks occupational wages and employment figures by region of the state, indicates that employment opportunities for technicians in Standard Occupational Codes (SOCs) related to mechatronics training will be greater in large metropolitan areas such as Houston, Dallas/Fort Worth, Austin and San Antonio than in smaller cities and towns. Based on site visits to Marshall, Sweetwater, Waco and Harlingen, less populated regions with manufacturing, aerospace and defense, information technology and other mechatronics-related industries will also experience demand for mechatronic technicians. Several companies in these regions are already expressing this workforce demand.

**Initiating a Mechatronics Program**

Many colleges in the state already conduct programs that provide students with technical training in many of the disciplines that define mechatronics. However, these programs tend to be taught as distinct degree programs by discipline. Exhibit ES.10 illustrates, conceptually, the relationship between existing mechatronics-related programs.
Exhibit ES.8. Relationship of Mechatronics to Existing College Programs

The range of technologies that can be taught in specific mechatronic programs will vary according to institutional resources and the needs expressed by targeted industries. Students will need to understand mechatronics broadly, however curriculum should consist of courses that holistically integrate broad topics as they are applied in common industrial practice in specific local and regional geographies. Exhibit ES.11 provides a comparison of four existing mechatronic Associate Degree programs in the United States and the respective core topics addressed by each.

**Faculty Qualifications**

Colleges that already have strong existing programs in electrical systems, electronics technology, robotics and automation, computerized control systems (instrumentation), industrial maintenance and engineering, electromechanical engineering and mechanical engineering are well positioned to develop mechatronic programs. However, even colleges with faculty in these disciplines will have to devote resources to restructuring the teaching of mechatronics as an integrated whole with specific industry applications.

Exhibit ES.9: Course Topics Addressed in Existing Two-Year Mechatronic Programs

<table>
<thead>
<tr>
<th>Topic</th>
<th>TSTC Harlingen (as proposed)</th>
<th>Sierra College (CA)</th>
<th>Alexandria Technical College (MN)</th>
<th>St. Clair County Community College (MI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Manufacturing</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Blueprint/Schematic Reading</td>
<td>Future</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CNC Machine Maintenance</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNC Machine Programming</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CNC Machine Troubleshooting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Computer Integrated Manufacturing (CIM)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Computer Programming (C, C#, etc.)</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
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</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Topic</th>
<th>TSTC Harlingen (as proposed)</th>
<th>Sierra College (CA)</th>
<th>Alexandria Technical College (MN)</th>
<th>St. Clair County Community College (MI)</th>
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<tbody>
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<td>Computer-Aided Design (CAD)</td>
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<td>x</td>
<td>x</td>
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<tr>
<td>Conventional Machining/Fabrication</td>
<td>x</td>
<td>x</td>
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<td></td>
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<tr>
<td>Electric Motors</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electrical Instruments &amp; Measurements</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electrical Motor Control</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electrical Wiring &amp; Installation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electricity &amp; Electrical Systems (AC/DC)</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Electro-Fluid Power</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electronic Drives</td>
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<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electronics</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fluid Power</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Foundational Mathematics</td>
<td>x</td>
<td>Pre-Requisite</td>
<td>Pre-Requisite</td>
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<td>Foundational Science</td>
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<td>Hydraulics</td>
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<td>x</td>
<td>x</td>
<td>x</td>
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<td>Internetworking</td>
<td>x</td>
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<td>Introduction to Computers</td>
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<tr>
<td>Lubrication</td>
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<td>Maintenance Practices</td>
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<td></td>
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<tr>
<td>Mechanical Drives</td>
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<td>x</td>
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<tr>
<td>Preventative Maintenance</td>
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<td></td>
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<tr>
<td>Programmable Logic Controllers</td>
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<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Robotics</td>
<td>Future</td>
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<tr>
<td>Semiconductor Electronics</td>
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<td>Servo Control</td>
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</tbody>
</table>

**Mechatronics Training Products and Competitions**

It is essential that colleges interested in establishing mechatronic programs provide students with laboratory facilities and opportunities for applied learning and hands-on experience. There are a number of options that colleges interested in establishing mechatronic programs can pursue in order to acquire suitable laboratory and training facilities. These options include dedicated trainers manufactured by companies such as Amatrol, Lab Volt and equipment donated from industry.
The trainer, which can be used by two students at a time, encompasses integrated training in hydraulics, pneumatics, mechanical drives, electrical wiring, programmable logic controllers, electronics and electronic control. The cost of a one-cell Amatrol laboratory trainer system used in the new Texas State Technical College Harlingen mechatronic program is approximately $200,000.

Lab-Volt’s Flexible Manufacturing System is another example of a modern Mechatronics trainer that integrates Programmable Logic Controllers (PLCs), electrical and mechanical actuators, motion control systems, sensors, vision systems, bar coding and numerous advanced interfacing techniques.
Colleges considering mechatronic programs may also use Internet-based virtual training modules and PC-based simulations to augment physical lab facilities. Amatrol and Lab-Volt have developed virtual learning systems that are available in addition to the printed curriculum materials that accompany their trainers. The virtual versions of the training materials have the same content as the printed versions, plus they include 3D simulations and interactive activities that have the same look and feel of the physical trainers.

The virtualization of the real world hardware and control systems enable simulated components to be interconnected for simulated exercises and lessons. Virtualizations, simulations and video game-based techniques should be considered in addition to traditional web and distance training methods. Continuing education outreach and market development with virtual classrooms (and simulations) should be considered for technicians in the workforce who want to upgrade from legacy systems to mechatronics technicians.

Another option to support mechatronics education is the use of an introductory robotics platform such as Qwerk from Austin-based Charmedlabs.com. Developed in collaboration with the Mobile Robot Programming Lab at Carnegie Mellon University’s Robotics Institute, this robot is a second generation of the personal rover and was developed to “catalyze creativity, foster technological empowerment, and inspire learning by transforming robotics into an accessible and collaborative tool for exploration.” When Qwerk is combined with CMU’s TeRK free software, a powerful and affordable mechatronics introductory platform is available for $349. When Qwerk hardware is combined with TeRK software and “robot recipes” from www.terk.ri.cmu.edu one can build a Telepresence Robot for $550.
Additional resources for college and secondary education include kits and competitions. See Appendix E.

**Industry and Education Partnership to Be Leveraged**

There are a number of industry and education associations available to provide advice and assistance to colleges considering the initiation of mechatronic programs. These include:

**National Science Foundation Advanced Technological Education Program**

The National Science Foundation (NSF), through the Advanced Technological Education (ATE) program, supports projects that develop technicians for advanced technology industries. The program supports the improvement of technical education at both the two-year college and secondary school levels through curriculum development and faculty training programs. ATE centers support collaboration among not only educational institutions, but also industry partners through formal cooperative agreements. By mandate, ATE centers must provide nationally-usable model curriculum for other institutions.
Society of Manufacturing Engineers Manufacturing Education Program

The Society of Manufacturing Engineers Manufacturing Education Program (MEP) supports the efforts of educational institutions to develop and improve manufacturing, engineering and technology education programs. Through academic-industry cooperation, SME’s goal is to increase manufacturing productivity.

Department of Labor Advanced Manufacturing Integrated Systems Technology Grants

The Department of Labor Advanced Manufacturing Integrated Systems Technology (AM/IST) grants are part of the President’s High Growth Job Training Initiative for Advanced Manufacturing. The program works with industry to identify critical technical workforce gaps and then constructs and replicates successful training models that address targeted gaps. The grants are awarded to regional entities that involve the cooperation of employers, educational institutions and the public workforce system. Texas State Technical College Harlingen received a $1 million grant from the program to establish an Integrated Systems Technology Laboratory (IST). The college will make extensive use of the laboratory in their new mechatronic program.

Conclusion

Mechatronics requires an evolution from unskilled to skilled labor in many industry and manufacturing environments. In fact, some argue that the demand for technicians trained and skilled in these new areas of electronic control is in excess of the demand for basic mechanical skills (Coyle, 2006). This trend toward multi-craft represents an opportunity; however, if we fail to act, Texas risks missing a great economic and technological wave which is transforming the nature of work from unskilled to skilled labor and technology education from what was once considered trade and vocational to highly advanced career and technology education.
Chapter One: Recommendations

Key Findings

1) Texas employers increasingly require “multi-craft” technicians. Our research shows that employers across industry segments increasingly require multi-craft technicians with integrated skills related to the application of intelligent mechanical systems. This evolving industry demand, impending workforce shortages, technology evolution and waning enrollment in Science, Technology, Engineering and Mathematics (STEM) programs are compelling drivers for some colleges to develop integrated mechatronic programs to meet targeted industry demand.

2) 2,058 job openings will be created in mechatronics-related Standard Occupational Codes (SOCs) annually through 2012. Of these jobs, 64% (1,331) will come from the replacement of existing workers. Many incumbent workers have achieved competencies in mechatronics through on-the-job experience or company training. As incumbent multi-craft technicians retire, it will be difficult to replace these employees because Texas lacks sufficient integrated multidisciplinary mechatronics educational programs.

3) College program directors in areas such as robotics and automation indicate that they have no problem placing their graduates in high-paying positions (at least $35,000 per year). The problem they face is attracting students to the program and graduating students for hire. A significant part of the problem is that students and their primary influencers are often misinformed about career opportunities in manufacturing and technical fields.

4) Mechatronics engineers, technicians and operators are required across all of Governor Perry’s targeted industry clusters; however, the term “mechatronics” is not broadly recognized by industry, education, workforce or economic development practitioners. Multi-craft and mechatronics represent an excellent opportunity to organize a cross cluster initiative.

5) Today, mechatronics is evolving to include the development of micro-, meso-, nano- and bio-mechatronic systems which interface with and control physical, chemical, biological and neurological processes. Furthermore, mechatronics is a foundational manufacturing platform for systems in the size range between one micro meter and one nano meter. Therefore, mechatronics is important in terms of traditional manufacturing and it is also the foundational manufacturing platform for advancements in emerging technologies and industries.

6) The US has been slow to develop mechatronics educational programs. Today, however, Texas has an opportunity to lead the development of mechatronics educational initiatives in the US and to lead the world by integrating related industry, education, workforce and economic development initiatives related to mechatronics.
Methodology

The information, assessments and recommendations included in this report are supported by five types of data:

- A review of pertinent primary and secondary research.
- A survey of Texas industry conducted by Technology Futures, Inc. (TFI) and Texas State Technical College (TSTC) Emerging Technologies.
- Interviews with directors of existing and planned college programs in the area of mechatronics and representatives of companies interested in hiring graduates of such programs.
- A panel of experts consisting of representatives from industry and colleges.
- TSTC Emerging Technologies and TFI’s previous experience in conducting projects related to emerging technologies and mechatronics.

In conducting the review of pertinent primary and secondary sources, dozens of reports, professional journals, news reports and curricula descriptions from existing mechatronic programs were gathered and reviewed.

The industry survey was designed primarily to target Texas employers with experience in the training and employment of college graduate technicians. The survey included 17 questions involving primarily employment projections (salaries and demand) and required KSAs. Invitations to participate in the survey were sent electronically to over 300 companies. Representatives of 39 companies participated in the survey, including companies that utilize mechatronic products and processes in semiconductor manufacturing, oil and gas refining and power generation and transmission. (For more information on this survey, see Appendix A.)

Additionally, 16 formal interviews were conducted, in addition to a number of informal discussions. The individuals interviewed included the director of the new Texas State Technical College Harlingen mechatronic program; the vice presidents of learning at Texas State Technical College Harlingen, Waco and West Texas Sweetwater; industry representatives; the head of the robotics department at the University of Texas at Austin; and three directors of out-of-state mechatronic programs. (A complete list of interview subjects is presented in Appendix B.)

In conducting this analysis, the TFI team was also able to call upon its own experience in similar studies, including analyses conducted for the Columbus (Indiana) Economic Development Board, the Texas State Technical College System and the National Security Agency. TSTC Emerging Technologies contractors (Eliza Evans, Ph.D. and Jim Brazell) were able to draw on experience in performing research for the IC² Institute and in writing M2M: The Wireless Revolution for TSTC.
Recommendations for Community and Technical Colleges and the K-12 Educational System

1. **Determine feasibility of integrating existing programs to develop mechatronic degree and certificate programs.**

Community and technical colleges (Colleges) with strong existing programs in electrical systems, electronics technology, robotics and automation, computerized control systems (instrumentation), industrial maintenance and engineering, electromechanical engineering and mechanical engineering are well positioned to develop mechatronic programs. Many colleges in the state already conduct programs that provide students with technical training in these disciplines, but these programs tend to be taught as distinct programs. Our research shows that employers increasingly require multi-craft technicians with integrated Knowledge, Skills and Abilities (KSAs). This evolving industry demand, impending workforce shortages and waning enrollment in Science, Technology, Engineering and Mathematics (STEM) programs are compelling drivers for colleges to develop integrated mechatronic programs.

The ability of colleges to institute a mechatronic curriculum successfully will depend on three factors: the qualifications of the current faculty with regard to the multidisciplinary integration of related mechatronic disciplines, the availability of suitable laboratory facilities and the local need for multi-craft mechatronic technicians. Outreach should include the entire system of influencers including employers, primary, secondary and post secondary educational institutions (especially counselors, Career and Technical Education Faculty and Principals), students, parents, workforce boards and economic development organizations.

2. **Establish liaison with the new mechatronic program at TSTC Harlingen.**

Texas State Technical College Harlingen launched the first Texas mechatronic degree program in 2006. This program integrates existing electromechanical, electronics and industrial maintenance curricula. This program can serve as a model for similar programs at other colleges. At its most advanced, mechatronics is an enabler to restructure and reorganize the teaching of science, engineering and technology around common principles. **This type of “transdisciplinary” reorganization is called for by the National Council on Competitiveness, the National Science Foundation and the US Departments of Education and Labor, among others.** In addition to reorganizing for innovation at the college, Harlingen is planning deeper reach in to the K-12 system to support teacher professional development and students through ongoing activities such as tours, lectures, in-classroom support and special summer programs.

3. **Assure that college programs keep abreast of mechatronic employment developments.**

In addition to the possible establishment of distinct mechatronic programs, developments in mechatronics will have a profound effect on the required KSAs of technicians who graduate from many different traditional programs including
automotive maintenance, electronics technology, HVAC systems, industrial maintenance, electromechanical technology, robotics and instrumentation, among others. In fact, many observers feel that a number of these existing programs could be revamped by the inclusion of subjects that characterize mechatronics. One of the ways that colleges can stay abreast of developments in this area is by establishing close relationships with those companies and other groups that will employ related college graduates. Such relationships may involve industrial internships for college instructors and industry sponsored design projects that are contracted to colleges and completed by students with guidance from instructors and industry mentors.

4. Offer programs that accommodate retraining for both incumbent and dislocated workers.

A number of technical and economic forces, including the increasing use of automation and robotics within the manufacturing environment and the outsourcing of significant manufacturing operations to foreign countries, have put many dislocated and even incumbent manufacturing workers at risk. Many traditional manufacturing jobs have or may become dated and obsolete as a result of these developments. Furthermore, the National Council on Competitiveness estimates that 100 million new jobs will be created in the 21st century at the intersection of disciplines rather than in individual disciplines. Mechatronics technicians exhibit this multi-disciplinary or multi-craft requirement today and they are in high demand across all of Governor Perry's targeted high growth industries. Mechatronics can provide incumbent and dislocated workers with skills to broaden job and career opportunities. Graduates with prior industry experience are especially attractive to employers because they already possess industry experience that many traditional students lack. Texas should support and fund training that leverages prior industry experience with highly sought after multi-craft skills in mechatronics.

5. Support awareness and outreach programs that publicize the attractiveness of mechatronic career pathways.

Although there are strong indications that career employment opportunities for mechatronic engineers and technicians will grow, few K-12 students, faculty members or career advisors in the state are aware of these opportunities. Awareness and outreach programs are excellent ways of addressing this problem and educating students about possibilities related to mechatronic employment. These programs might include the following activities:

- creating a Texas grand challenge in mechatronics that elevates competitive robotics to a similar status as academic decathlon, speech/debate and athletics while lowering the barrier to entry for Texas K-12 schools (i.e., travel costs, etc.);

- support for Texas primary and secondary schools to participate in existing competitive mechatronics and robotics competitions such as Mechatronics Olympics, SkillsUSA, US For Inspiration and Recognition of Science and Technology (US FIRST), BotBall, BEST and Engineering And Robotics Learned Young (EARLY); and,
6. **Formalize and expand mechatronics and robotics programs in Texas K-12 schools.**

Many Texas K-12 schools have integrated “competitive robotics” as a means of developing student interest and experience with applied engineering and technology. Because these programs start as early as first grade and continue through college, robotics presents an opportunity to grow an established community of practice rather than starting from scratch. It is important to note, however, that current competitive robotics and mechatronics programs often lack academic rigor in favor of figuring it out as you go. *Although the authors are strong advocates of constructivist, constructionist and inquiry-based learning, we suggest that Texas take the lead in formalizing multidisciplinary education at the elementary, middle and high school level. Existing robotics programs provide a starting point but need resources including:*

- curricula development to formalize multidisciplinary applications and teaching of mechatronics, micro-mechatronics, nano-mechatronics and bio-mechatronics;
- **general systems approach to curricula which in phase one integrates the teaching of mathematics, physics, computer science, engineering and design and in phase two integrates the previous disciplines with biology and chemistry;**
- curricula alignment with Texas Essential Knowledge and Skills (TEKS) and Achieve Texas;
- teacher professional development programs, internships and conferences;
- online resources that help build collaborations, share best practices and expand programs among primary, secondary and post-secondary educators;
- funding for laboratory equipment, workbenches and consumables;
- dual enrollment and Tech Prep courses that allow high-school students to take courses that grant credit toward a college degree; and
- development of a state-wide articulation agreement that guarantees mechatronics college and university credits will be accepted by all Texas post-secondary schools with related programs.

7. **Use “Career Foundation Model” to support mechatronic education.**

Dick Whipple, Director of Curriculum and Instruction at Southwest Texas Junior College has proposed a Career Foundation Model that would permit students to complete their foundational academic and technical courses in a one-year period at one college and then complete their occupational area technical courses at
another college. These partnering agreements would be important for a number of reasons:

- The resources, i.e., faculty, equipment and materials, needed to start a mechatronic program are extremely expensive, which may preclude many colleges from initiating programs. The Career Foundation Model would give students at resource-limited colleges increased options and opportunities for specialized and high-cost mechatronic training. The effect of this would be to increase educational opportunities for many students in the state, especially in those areas underserved by technical college programs while increasing the potential pool of available multi-craft candidates to industry.

- The Career Foundation Model can provide students with greater latitude in selecting an area of concentration within mechatronics. There are variations in how mechatronics can be taught at specific colleges. Most of this variation will be a function of industry demand. Using a Career Foundation Model, students can complete their foundational mechatronic training at one college and then seek industry-specific mechatronic training at other colleges. This option gives students greater freedom in shaping their career trajectories. The constraint of selecting a certain specialization just because it is the only one offered at a student’s home college is thereby lessened.

8. **Colleges without existing programs in mechatronics-related disciplines should be prudent about initiating such programs.**

The demand for mechatronics-related technicians varies greatly between geographic areas in Texas. Moreover, the cost of initiating such a program can be very costly. Therefore, colleges without existing infrastructure in this area should very carefully consider the costs and benefits of starting a mechatronic program. The “Career Foundation Model” discussed above may provide a more cost effective entry into mechatronics through collaborations with other colleges.

**Recommendation for the Texas Leadership Consortium for Curriculum Development (CCD)**

As part of this project, the authors submitted a recommendation to the Texas State Leadership Consortium for Curriculum Development (CCD) that the Consortium fund the development of a core curriculum (i.e., CFM) in mechatronics. Although the CCD has been dissolved, the authors believe that it would be advantageous for the Texas Higher Education Coordinating Board (THECB) or other state body to seriously consider this recommendation. (For a discussion of the rationale behind this recommendation, see Appendix C.)

**Recommendations for Texas State Government**

Governor Rick Perry has enthusiastically committed the resources of the state to supporting programs that bolster the international competitiveness of Texas industry.
Mechatronics touches all of Governor Perry’s targeted high growth industries. The Governor and the Texas Industry Cluster Initiative should consider mechatronics as an organizing framework (among others) to integrate cross cluster activities.

9. *Integrate mechatronic education and industry into existing and planned statewide economic development efforts designed to support established companies and spur new business formation.*

- Support curriculum development, dual enrollment, articulation and faculty professional development among educational institutions and industries, including K-12, community and technical colleges and universities. Such a function is critical; several employers that we interviewed and surveyed indicated that there was a critical shortage of mechatronics-skilled employees increasingly needed by Texas industry.

- Partner with the Texas Manufacturing Assistance Center, the statewide manufacturing extension service, to become a clearinghouse for Texas industry regarding the practical application of mechatronic principles. Researchers and industry representatives can cooperate in determining how mechatronic approaches and products could be used to solve specific problems and create opportunities in Texas companies. These efforts would allow Texas industry to achieve efficiencies and bolster their economic competitiveness.

- Identify critical industry-identified competency gaps in mechatronic training and facilities in the state and fund the development and expansion of training and recruiting programs as necessary.

- Initiate public relations campaigns that increase public awareness of the attractiveness of mechatronics-related careers.

- Place special emphasis on the relationship between mechatronics in traditional manufacturing and emerging manufacturing related to micro-to-nano scale systems. This tactic can unify the state’s fractured relationship between traditional manufacturers and advanced technology manufacturers. Common ground is difficult but possible with a unifying framework such as mechatronics that promises greater economies of scale, efficiency and cost reduction. Perhaps more important, cross-cluster innovation can become a differentiator for Texas and an example for the world.

There are several centers in the United States, including the Minnesota Center for Advanced Manufacturing Automation, which could serve as models for related activities. Although these programs are models, *Texas can lead by developing a systemic initiative that connects mechatronics in use today with micro-, nano- and bio-mechatronics to achieve a fully integrated system for innovation and the production of human capital necessary to lead the world in the application of 21st century science to the resolution of global challenges and economic opportunities.*
Conclusion

In many ways, the technological convergence evident in mechatronics is the distinguishing characteristic of 21st century innovation. Companies of every size in multiple sectors will increasingly require operators, technicians, engineers, designers and even scientists fluent in mechatronics. Intelligent mechanical and electronic systems, from large automated industrial machines to microscopic actuators, are already having an impact on numerous industries and hold great promise for future applications. The integration of academic disciplines for students (knowledge mergers), the integration of applied skills for workers (skill mergers) and the integration of distinct occupations (job mergers) present an opportunity for Texas to lead the world in anticipating and acting on the knowledge that 21st century innovation is characterized by systemically restructuring education and work.
Chapter Two: Overview of Mechatronics

Mechatronics

Mechatronics is a system of technologies which integrates mechanical and electrical systems through control systems and information technology. Mechatronics is another way of saying “intelligent mechanical systems.”

The term mechatronics, which is a combination of “mecha” of mechanisms and “tronics” of electronics, was coined in 1969 by Tetsuro Mori, a senior engineer at the Japanese company Yaskawa, a manufacturer of electric motors and motion control products. At its heart, mechatronics involves the use of computers and control systems to direct the operation of mechanical systems. In application, mechatronics relates to the optimization of mechanical elements such as valves, lift arms, motors or engines through the use of electronic control networks composed of devices such as sensors, programmable logic controllers, embedded processors and the necessary software instructions (i.e., “hardware under the control of software-based systems”).

The number and type of systems that can be fairly considered mechatronics is broad in both application and complexity and spans many industry sectors. These systems include everything from the household clothes dryer that uses a moisture sensor to turn itself off when a load of clothes is dry to a complex, highly-automated wafer stepper that produces state-of-the-art integrated circuits in a thousand step semiconductor manufacturing environment. Other representative mechatronic systems include “household name” items such as hard disk drives, ATM machines, anti-lock braking systems for automobiles and even casino slot machines.

Furthermore, mechatronics is advancing to include micro-, meso- and nano-scale systems and the means of manufacturing these systems. For example, bio-mechatronic systems include the cochlear ear implant for the hearing impaired and micro-to-nano scale manufacturing systems for Micro Electro-Mechanical Systems (MEMS) and nano systems are generally dependent on mechatronic assembly and packaging tools from companies such as Dallas-based Zyvex Corporation.

There is no mechatronics industry sector; rather, it is an enabling approach to technology that is increasingly applied in a number of economic sectors including: Biotechnology, Life Science & Medical; Electronics & Applied Computer Equipment; Telecommunications & Information Services; Distribution, Transportation & Logistics; Heavy & Special Trade Construction; Energy, Mining & Related Support Services; Petroleum Refining & Chemical; Transportation Equipment; Production Support & Industrial Machinery; Agriculture, Forestry & Food; Aerospace, Homeland Security and Defense.
There are a number of advantages associated with the use of mechatronics in the design of physical systems. These advantages include not only the ability to replace many mechanical systems with electronic systems, which introduces greater reliability and flexibility into a system, but also the ability to monitor and change the operation of a system based on information collected during its use (Ratnaweera, 2006). For example, the Toyota Prius Hybrid automobile optimizes gas mileage using mechatronics automation techniques.

**Exhibit 2.2. Advantages of Mechatronics Systems**

<table>
<thead>
<tr>
<th>Traditional</th>
<th>Mechatronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centralized processing &amp; control</td>
<td>Hybrid Control: Adaptive and/or Multi-architecture control (e.g., Centralized, Centralized processing &amp; control Decentralized and Distributed)</td>
</tr>
<tr>
<td>Inspection/QA stage toward the end of manufacturing processes</td>
<td>In-process automatic inspection</td>
</tr>
<tr>
<td>Bulky componentized systems</td>
<td>Compact integrated systems</td>
</tr>
<tr>
<td>Lack of accuracy, backlash</td>
<td>Precision displacement control through adaptive control systems and servo motors</td>
</tr>
<tr>
<td>Complex mechanical mechanisms</td>
<td>Replacement of many complex mechanical components and/or systems with electronic, computer and/or software systems</td>
</tr>
<tr>
<td>Manual controls and data collection</td>
<td>Automated control, data collection and reporting</td>
</tr>
<tr>
<td>Constant speed drives</td>
<td>Variable speed drives</td>
</tr>
<tr>
<td>Mechanical Systems</td>
<td>Mechanical, Computer, Electronic, Software, and/or Network interface and/or control of physical, chemical, biological and/or neurological systems,</td>
</tr>
</tbody>
</table>

Sources: Adapted from Asanga Ratnaweera, Department of Mechanical Engineering, University of Peradeniya
**Mechatronics Systems**

**Robotics**

In general, a robot is considered to be a mechanism guided by control systems that can sense and gather information from its surroundings in order to automatically and repeatedly perform complicated and often repetitive tasks. As a result, many observers view the field of robotics as the ultimate application of mechatronic principles.

First-generation robots, which were unable to coordinate the movement of their various arms without sensory feedback/control systems, benefited greatly from multidisciplinary research in kinematics, dynamics, controls, sensor technology and programming (Ashley, 1997). This same multidisciplinary research that allowed robots to become more flexible has been used to improve the performance of all kinds of machines in applications such as:

- Automated welders and painters in automobile manufacturing plants.
- Mobile bomb detector and detonation units for police SWAT teams.
- Even as packaging tools to place and properly align chocolate confections in gift boxes.

**Exhibit 2.3. Robotic Welding Line in Automobile Assembly Plant**
Computer Aided Drafting/Computer Aided Manufacturing (CAD/CAM)

Computer numerically controlled (CNC) machining tools, such as lathes and mills, use complex control systems and computer programming tools to automate the cutting, bending and machining of parts from stock material. Typically, a technician produces an engineering diagram of the component they want to fabricate using Computer Aided Drafting (CAD) software such as AutoCAD. Based on this diagram, a program generates tool steps to make the part using Computer Aided Manufacturing (CAM) equipment. A complex feedback control system uses various servomechanisms (i.e., electromechanical devices) to precisely move the tool through the proper machining steps. Although manual machining equipment and skills are still used and in demand today, the use of CAD/CAM tools is increasingly changing the manufacturing industry. The automation of machining processes has introduced considerable improvements in efficiency, consistency and quality in manufacturing parts and has dramatically reduced the contribution of human error to problems inherent in the production environment (Equipment MLS, 2006).

Advanced Digital Manufacturing (ADM)

In contrast to Computer Numerically Controlled (CNC) machining techniques that build a part from the top down by removing material, Advanced Digital Manufacturing uses (ADM) layered manufacturing techniques to build a part from the bottom up through the addition of successive layers of material. In a typical digital manufacturing machine, a movable source simultaneously deposits and sinters various polymeric and/or metal powders into a shape dictated by computer instructions that outline the shape of the part to be made. A number of automation and control tools are used to precisely and accurately move the source through the proper geometry. ADM often allows designers to produce parts or prototypes that might be very difficult (i.e., expensive) or impossible to produce with traditional machining processes.

For more technical and workforce analysis related to ADM, see TSTC publication Emerging Technology Programs: ADM, Hybrids, Computer Forensics and MEMS at http://system.tstc.edu/forecasting/.

Supervisory Control and Data Acquisition (SCADA)

Supervisory Control and Data Acquisition (SCADA) systems are legacy computer-based monitoring and control systems that centrally control, display and store information from remotely-located data collection transducers and sensors to support the control of equipment, devices and automated functions. A SCADA system permits an operator to monitor and control devices, such as valves and generators, distributed among various remote sites.

SCADA systems are currently being used by electric utilities, oil and gas pipelines, water and wastewater distribution and treatment systems, chemical and product manufacturing (process control), rail yards, airport runway lighting systems and a host of other process operations. SCADA systems are currently used by essentially
100 percent of electric power production, transportation and distribution systems and by about 90 percent of all oil and gas pipelines in the United States (Newton, 2005).

Increasingly, system analysis and field equipment control is becoming distributed and decentralized (some hybrid architectures are also emerging which aggregate multiple network architectures) as advances in semiconductor processing power have allowed more intelligence to be built into devices such as programmable logic controllers. In some SCADA systems, especially new ones in the process control industries, programmable automation controllers (PACs) are being used to integrate software and hardware into a single mechatronic system combining programmable logic controls, remote input/output, motion control, drives and other devices. The PACs, the distributed “brains,” are moving closer to the muscles (“actuators”) of such systems, which means that outlier or failure operating conditions can be responded to much more quickly, resulting in much more desirable outcomes.

For more technical and workforce analysis related to process control, see TSTC publication Machine-to-Machine: The Wireless Revolution at http://system.tstc.edu/forecasting/.

**Mechatronics Industry Applications**

Mechatronic systems are prevalent in US industries and workforce clusters such as: Biotechnology, Life Science & Medical; Electronics & Applied Computer Equipment; Telecommunications & Information Services; Distribution, Transportation & Logistics; Heavy & Special Trade Construction; Energy, Mining & Related Support Services; Petroleum Refining & Chemical; Transportation Equipment; Production Support & Industrial Machinery; Agriculture, Forestry & Food; Aerospace, Homeland Security and Defense. Below is a survey of a few industry applications of mechatronics:

**Automotive**

Today’s automobiles are complex, mobile, semi-autonomous mechatronic systems that rely on sophisticated in-car monitor and control systems for their operation. These systems include electronic fuel injection, anti-lock braking, cruise control, telematics (OnStar) and tire pressure monitors. Increasingly, automobile manufacturers are investigating “drive by wire” technologies as a means of replacing mechanical connections such as push-rods, overhead cams and steering columns. Their plan is to remove the mechanical connections between the driver operated controls in a car (e.g., gas and brake pedals, steering wheel) and the devices that actually do the work (brakes, steering column). In such a system, inputs from the driver are sent to a central computer that makes decisions about the best combination of outputs from the various devices and sends out a set of instructions. The touted advantage of such systems is that better control over variables, such as fuel consumption or traction control, can be achieved. Additionally, in safety systems such as anti-lock braking and steering, mechatronics-based systems provide faster response to critical environmental conditions than a human operator can provide (Spong, 2006).

Many of these concepts are being demonstrated in currently available hybrid vehicles, which are powered by both an internal combustion engine and an electric
These vehicles use an energy management system (EMS), run by various feedback, control and processing elements, to efficiently distribute power from the internal combustion engine and electric motor to the drive train and to recharge the electric battery. The EMS works to distribute power so that the internal combustion engine works under optimal conditions and that the motor acts as a generator during braking. These complex systems allow hybrids to achieve design objectives, such as high fuel economy and low emissions (Elliott & Vanston, 2004). The Toyota Prius, for example, is certified as an Advanced Technology Partial Zero Emission Vehicle (AT-PZEV) or as having near zero emissions and zero evaporative emissions.

Exhibit 2.4. Toyota Prius Hybrid Vehicle

For more technical and workforce analysis related to Hybrids, see TSTC publication Emerging Technology Programs: ADM, Hybrids, Computer Forensics and MEMS at http://system.tstc.edu/forecasting/.

Aviation and Aerospace

Modern airplanes use complex pneumatic and hydraulic systems to provide power for critical functions. Typically, these systems are driven by high-temperature, high-pressure “bleed air,” which is diverted from the plane’s jet engines and must be run through a series of valves and precoolers before it can be used. From an energy balance standpoint, this process is inefficient because it removes mass airflow (i.e., energy) from the engine, resulting in decreased fuel efficiency. Additionally, the use of pneumatics and hydraulics requires miles of piping that is not only expensive to install but also difficult to inspect for safety purposes (Wallace, 2004).

Some new airplanes, including the Boeing 787 DreamLiner commercial model, propose to replace a number of pneumatic and hydraulic systems with mechatronic systems driven by electric generators powered by the plane’s jet engines. Examples of the new electrically driven subsystems are described below (Wallace, 2004):

- Electrically driven hydraulic pumps will replace air-driven pumps that raise and lower the hydraulic landing gear.
- The deicing system on the plane’s wings will be heated electrothermally rather than pneumatically.
• Brakes powered by electrically driven actuators are being used to replace brakes powered hydraulically.

The ultimate advantage of these new technologies is that the 787 DreamLiner will burn significantly less fuel per passenger and fly farther without refueling than similarly sized airplanes. Thus, longer flights without time consuming layovers will be possible between international destinations.

**Automated Consumer Equipment**

This is an extremely broad area of application that includes Automatic Teller Machines (ATM) equipment, printers, compact disc players, cash registers, vending machines and copy machines. New and interesting applications include so-called “smart” consumer products that combine information technologies, sensors, actuators and vision and hearing systems to adjust their operation and uniquely meet the needs of consumers. An example of such a system is an “in-house” robot that elderly homeowners can use to assist with various tasks including dispensing medicine according to preprogrammed schedules and with the performance of simple diagnostic procedures such as blood pressure measurement.

**Biotechnology**

Mechatronics tools are increasingly used to conduct research and product development in biotechnology environments. Applications of mechatronics/robotics in biotechnology include:

• DNA and protein sequence analysis
• High-throughput molecular screening and drug discovery systems
• Bio-sample preparation (blood, sputum, gynecological, colorectal, fine needle aspirates)
• Production and analysis of DNA and protein microarrays
• Lab-on-a-chip chemistry analysis systems
• Functional analysis of living cells
• Combinatorial chemistry
• Protein crystallography
• Exploring molecular and cell biology (on Earth & other planets)

The use of mechatronic tools is dramatically increasing the productivity of biotech research by freeing valuable researchers from nonproductive, repetitive, mundane tasks and decreasing the amount of time (i.e., money) it takes to set up and conduct large-scale experiments (Gwynne & Heebner, 2005). Additionally, the use of such tools removes a significant amount of the “human element” from certain laboratory
procedures, which helps assure that large-scale experiments can be conducted in a manner that is reproducible and less prone to errors.

For more technical and workforce analysis related to Biotechnology, see TSTC publication Biotechnology: A Technology Forecast at http://system.tstc.edu/forecasting/.

**Semiconductors and Computers**

The exorbitant cost of constructing semiconductor fabs to produce integrated circuits and Micro-Electro-Mechanical Systems (MEMS) has driven the semiconductor industry to place great emphasis on optimizing the efficient use of resources. The efficient movement of material, such as wafers, through a fab largely determines the productivity of a semiconductor manufacturing plant (Samsung, 2006). Mechatronics, specifically automation, is an important tool that semiconductor manufacturers utilize to accomplish this goal. In this environment, automation can be divided into two parts—information automation and material automation.

Information automation is related to the use of industrial networks to transmit information about the proper processing of a wafer throughout the production cycle. Material automation is handled by Automated Material Handling Systems (AMHS), which actually physically move the wafer through the various process steps in a fab. Both systems work together to ensure that wafers are delivered to a step in the manufacturing process at exactly the right moment, which optimizes the utilization of expensive process tools. Tools of the AMHS include wafer handling robots, tool buffers, equipment load ports and equipment front-end assemblies (Van Antwerp, 2004).

**Exhibit 2.5. Cleanway 07® Overhead Monorail Wafer Transport**

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**Alternative Energy**

In addition to concerns about the environment, rising energy costs have fueled an ever-growing interest in the use of alternative energy sources such as hydrogen, wind and Combined Heat and Power (CHP) as a means of energy generation and recycling.

Fuel cell systems integrate mechanical, electrical, electronic control and even chemical subsystems to convert hydrogen fuel sources, such as methane, into power. These subsystems work together to create electricity through an electrochemical process that is twice as efficient in generating power as conventional fossil fueled power plants and generates smaller quantities of greenhouse gases (Department of Energy, 2002). The ability of engineers to precisely control these various subsystems in a wide range of operating conditions, through the use of relays, control valves, pumps, compressor motors and programmable logic controllers is made possible by mechatronics (Stefanopoulou, 2004).

For more technical and workforce analysis related to Fuel Cells, see TSTC publication: Fuel Cells: A Technology Forecast at [http://system.tstc.edu/forecasting/](http://system.tstc.edu/forecasting/).

Wind is another potential source of energy that possesses many favorable characteristics; its use generates almost no pollution and it is renewable. Wind turbines use the wind to turn rotors connected to generators to produce power. These turbines are complex systems that utilize mechatronic design principles to efficiently generate power. These systems holistically integrate aerofoil and rotor design, control systems (programmable logic controllers), high voltage electricity principles (three phase power, motor control) and hydraulics to optimize the position of the rotors relative to the direction of the wind and to more efficiently transfer electricity to the transmission grid.

**Exhibit 2.6. Inside a Wind Turbine**

![Wind Turbine Diagram](Source: US Department of Energy)
Combined Heat and Power (CHP) is a form of “energy recycling” and is considered a category of alternative energy methods and techniques likely to advance significantly over the next three to five years. CHP implementations require technicians with integrated skills in electrical, mechanical and automatic control systems.

In CHP systems, thermal energy in various exhaust streams from power generation equipment is recovered for operating equipment for space and/or process cooling, heating or controlling humidity in facilities, by using absorption chillers, desiccant dehumidifiers, or heat recovery equipment for producing steam or hot water. CHP is a form of “Distributed Generation”. Distributed generation can be defined as “the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site of the meter.” (In Brazell, 2007)

CHP is used today in modern power plants and has matured in large industrial plants. CHP is in the early adoption phase in mid-tier markets including hospitals, universities, office buildings and manufacturing facilities and it is an emerging method in residential applications. Micro-CHP (mCHP) units for individual homes are now sold in Germany, Japan and most recently in the US CHP systems are known by a variety of acronyms: CHP, CHPB (Cooling, Heating and Power for Buildings), CCHP (Combined Cooling Heating and Power), BCHP (Buildings Cooling, Heating and Power) and IES (Integrated Energy Systems).

**Micro-, Meso- and Nano-Scale Mechatronics**

Today, mechatronics includes recently established fields such as bio-mechatronics and Micro-Electro-Mechanical Systems (MEMS) while also including other emerging technologies such as other micro-, meso- and nano-scale systems.

In general terms, nano-scale systems are one nanometer (10^-9 m), micro is 0.1 micrometer (10^-7 m) and meso is between nano and micro (Moyer, 2007). Application of mechatronics at these scales and across wet, dry and computational environments has yielded products that are on the market today and which are forecast to grow in importance economically and in terms of national security over the next decade. For example, MEMS components have been in projectors since 1996 and in TVs since 2002 and today they are pervasive in cell phones, digital cameras, gaming devices, laptops and other devices (Gale, 2007).

Today, mechatronics is evolving to include the development of micro-, meso- and nano-scale systems which interface with and control physical, chemical, biological and neurological processes. One such example is a nanobionic motor made of the bacterium e. coli from the University of Texas at San Antonio.
Exhibit 2.7. Nanobionic Motor from University of Texas at San Antonio

![Exhibit 2.7. Nanobionic Motor from University of Texas at San Antonio](Image)

**Nano Motor (45 nm wide)**  
Efficiency ~ 90-100%  
Output power ~ 2.9×10^{-4} pW  
Stall torque ~ 4600 pN-nm

Source: Image Courtesy of Mohamed Al-Fandi, Ph.D.

Mechatronics is a foundational manufacturing platform for systems in the size range between one micrometer and one nanometer. Therefore, mechatronics is important in terms of traditional manufacturing and it is also a foundational manufacturing platform for advancements in emerging technologies and industries. *Educational and economic development initiatives should be particularly integrative of mechatronics because of its prevalence within localized industry and its potential for wealth creation in new applications.*

The mechatronics system of technologies and knowledge represents a general systems network of knowledge reducible to a core set of interconnected educational principles which can scale from K-Ph.D. As such, **mechatronics can be leveraged as an organizing framework to restructure the teaching of Technology, Engineering, Arts (Design), Mathematics and Science (TEAMS) in order to engender the creative and innovative capacity of students and regional economies.**

Mechatronics is a good starting point for this integrative reformation because of early adoption in K-12 schools in the form of competitive robotics (see Appendix E) and because the general systems theory of mechatronics scales from physical systems that we can see and touch to biological, chemical and neurological systems which are invisible to the human eye. Using this tactic, mechatronics can be a foundational educational platform enabling young people to see and touch ideas and knowledge that scales from the world of physical robots to the infinitesimal world of micro-to-nano scale technology. All tolled, **the system of mechatronics knowledge represents a platform upon which to build human capital capable of thinking beyond prescribed questions and answers to solve problems in disciplines, across disciplines and beyond disciplines—human capital capable of innovation.**
**Bio-Mechatronics**

Biomechatronics is the integrated study of biology, mechanics and electronics. It concerns the interactivity of biological organs (including the brain) with electromechanical devices and systems (Adapted from Delft University of Technology, 2007). Bio-mechatronics represents the emergence of new human-machine interfaces and ultimately the creation of hybrid machines that interface with physical, chemical, biological and neurological systems. Bio-mechatronics technologies include biotechnology automation, bionics, bio-engineering, bio-sensor, bio-signal processing, intelligent control, BioMEMS, biomaterials, bio-informatics and bio-reactor engineering (Adapted from National Taiwan University, 2007). Examples of bio-mechatronic devices available today include the heart pacemaker/defibrillator and cochlear implant hearing aids.

**Exhibit 2.8. Bio-Mechatronics Today: Cochlear Ear Implant**

Source: Image Courtesy of Carle Clinic Association and Carle Foundation Hospital
On the horizon of bio-mechatronics research is a new generation of artificial limbs for amputees that can communicate with the user’s nervous system and mentally-controlled electrical muscle stimulators (Adapted from MIT, 2007).

**Micro-, Meso- and Nano-Mechatronics**

Micro-, meso- and nano-mechatronics is focused on automation processes and more efficient manufacturing, manipulation, prototyping and interaction with materials and systems between micro- and nano-scales. In other words, micro-, meso- and nano-mechatronics are the foundational experimentation and manufacturing platforms for technologies such as MEMS (micro-scale), nanobionic systems (meso-scale) and nano molecules (nano-scale).

Applications may include but are not limited to miniaturized robotics, sensors, actuators, fabrication techniques, integrated devices and systems, power sources and supplies, machining, fabrication and packaging (Adapted from IEEE, 2007). For example, nano-materials are used as electromechanical actuators such as Dallas-based Zyvex Corporation “probes and nanogrippers” capable of manipulating objects at the atomic scale.

**Exhibit 2.9. Micro-Mechatronics Today: MIT Nano-Tweezers**

Combined, micro-, meso- and nano-scale mechatronics enable a new era of design and control of physical, chemical, biological and neurological processes.
In mechatronics, Texas has discovered a single integrative thread which impacts current technologies, products and work environments in targeted industry clusters while connecting to the future technologies, products and work environments of emerging markets. Government, education and industry should respond with appropriate resources in a timely manner to capitalize on this strategic opportunity.

For more technical and workforce analysis related to nanotechnology, see TSTC publication Nanotechnology: A Technology Forecast at http://system.tstc.edu/forecasting/.

**Mechatronic Trends—Drivers and Constraints**

**Drivers**

The trend of replacing purely mechanical mechanisms with intelligent mechanical systems is well underway—expanding over the past 30 years. The reality, as the examples above illustrate, is that many technologies and the industrial settings in which they are produced or operate are already pervasively mechatronic in nature. Such systems offer a number of advantages including simplified mechanical design, greater reliability and cost effectiveness and the ability to adapt and optimize a product’s functionality during operations.

For example, manufacturing processes are becoming increasingly automated. This automation reduces the need for traditional “dark, dirty and dangerous” jobs on the production line. At the same time, the need for highly skilled and higher paid technicians increases. Costly and unfortunate safety incidents can be substantially decreased by reducing the number of unskilled labor on a production line and automating manual and repetitive tasks. These work environments have higher safety and offer a more compelling work environment for employees. Manufacturing facilities that do not retool to these principles may be unable to compete with cheap foreign labor. Moreover, companies that operate stereotypically “dark, dirty and dangerous” manufacturing facilities may have more difficulty recruiting and retaining talent.

The trend of embedding devices with more intelligence (i.e., embedded electronics) into mechanical systems is likely to increase as the performance of processors, memory, storage and bandwidth continue to increase while relative costs decrease. Additionally, standardized communication protocols and infrastructure, such as Internet protocol, field bus and Ethernet, will continue to simplify interconnections and control devices through industrial networks. These networks include “machine to machine” (M2M) networks that enable machines to control and monitor other machines.

To become proficient in their jobs, many incumbent technicians have achieved competency in mechatronics through on-the-job experience or company training. As workers who have developed mechatronics skills retire, educational programs which integrate mechatronics-related curricula and their graduates will become increasingly important to US National Competitiveness and US National Security.
Constraints

A tremendous amount of legacy equipment that is not enabled for industrial networking or electronic control systems is still in use (Black, 2006). A substantial amount of this equipment is not going to be replaced any time soon and presents a challenge to organizations trying to integrate mechatronics-enabled solutions into operational environments. Today, some mechatronic systems are heterogeneous and highly fragmented requiring proprietary operating systems and application software. This causes complexity and expense in the deployment of these systems.

Integrating and maintaining legacy and new systems is a labor intensive process and industry’s ability to incorporate new innovations to enhance their competitiveness will be in part dependent on Texas’ ability to produce an appropriately skilled multi-craft technical workforce. In addition to the technical issues, the use of mechatronic systems can create more complex safety and service issues for the technician and engineering workforce. For example, automobile technicians who service hybrid vehicles have to not only learn completely new skills related to the car’s complex computer controlled energy management systems and electric motors/generators, but also have to learn how to safely discharge the car’s high-voltage circuitry (.300 volts) before certain maintenance operations (Larsen, 2002).

There can be considerable expense in organizing mechatronics curricula and creating the necessary laboratories. Moreover, the transition to integrated mechatronics curricula may be difficult and time consuming for some institutions given a tendency toward specialization and fragmented disciplines.

During field interviews with employers, the authors discovered that labor union job divisions have sometimes been a barrier to the acceptance of multi-craft technicians. Asia and Europe have pursued integrated multi-craft technicians and engineers for over 20 years while in the US we are just now recognizing the potential of multi-craft mechatronics engineers and technicians.

Other constraints may include social, political, economic and moral barriers to the development of mechatronic systems that replace human-dependant cognitive and physical skills with intelligent machines. Finally, fear of creating human-machine integration such as bio-mechatronics and mechatronic control of physical, chemical, biological or neurological processes may encumber the development and/or acceptance of mechatronics technologies.

Importance of Mechatronics to Texas Workforce, Education and Economic Development

Perhaps a “best” industry example of this approach to technician education, training and development is seen in the automotive service industry. Historically, automobile “mechanics” required only training in the mechanical elements (i.e., engine, transmission) that governed an automobile’s operation. However, as automobiles became more “electronic,” especially with the addition of computerized on-board diagnostic (OBD) tools in the 1990s, automobile technicians have also had to become familiar with the electronics control systems that monitor and control a
car’s operation. **Effectively, automotive technicians are multi-craft mechatronics technicians.**

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**Ken Ryan, Alexandria Technical College**

There is a gradual transition in high-speed, highly-mechanical advanced packaging machines. A lot of the mechanics is coming out of those machines and being replaced with electrical/electronic control systems. The mechanics that is coming out includes line shafts and internal cams. These mechanical components, which require a lot of mechanical engineering design, are being replaced with servo motors, electronic line shafting and lots of networking of inputs and outputs. The companies that make and use such equipment will require more and more of what are referred to as mechatronics technicians.

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Colleges that train automobile service technicians have instituted training in these systems into their programs to better prepare their graduates for the workforce. The same trend is evident in many other program areas such as diesel and heavy equipment, instrumentation, process technology, industrial technology and maintenance and many others. **This is an example of how traditional “vocational” or “trade” schools are less relevant today. This old paradigm is being replaced by advanced “career and technical” educational programs. In fact, some argue that the demand for technicians trained and skilled in these new areas of electronic control is in excess of the demand for basic mechanical skills (Coyle, 2006).**
Chapter Three: Mechatronics Technicians

Mechatronics as a Career

As products and systems have become increasingly mechatronic, it has become necessary for technicians to become “multi-craft” technicians. Multi-craft technicians are familiar with all or most of the various systems associated with mechatronics. They are capable of performing traditional responsibilities of technicians, i.e., the installation, calibration, maintenance, troubleshooting and repair of equipment across integrated systems. Unfortunately, many entry-level technicians have graduated from programs that train just one or two of the areas that comprise mechatronics. Typically, incumbent technicians become proficient in mechatronic systems through on-the-job experience or company training. However, companies, in general, see significant value in people with formal mechatronic training.

Nick DeNardo, Instructional Design and Development Supervisor, Tokyo Electron Austin

Tokyo Electron (TEL) struggles to find employees with multidisciplinary skills. When TEL hires employees from tech schools they generally have expertise or experience in these areas—(mechanical, electronics, electrical or perhaps even computer science). Once those employees are hired, TEL has to work to bring them up to speed, at TEL’s expense, to a level of competency in the areas where they are lacking. A risk is that some will lack the aptitude for the new skills that we must teach them. We see the need for mechatronic training getting greater in the future because of the increasing automation of equipment.

Sixty-three percent of survey respondents agree that in order to maintain competency, most technicians have had to acquire mechatronic skills sets, primarily through On-the-Job-Training (OJT).

Job Titles

Mechatronics is a fairly new term in the United States. As a result, it is rare to see Texas employers ask specifically for mechatronic graduates. Employers were more familiar with the approximant term “multi-craft”. Students who graduate from existing mechatronic programs fill positions with existing job titles and standard occupational codes such as semiconductor technician, electromechanical engineering technician or process technician (chemical industry). Texas businesses should request the Texas Workforce Commission and the US Bureau of Labor Statistics consider the creation of a mechatronics multi-craft Standard Occupational Code as the trend toward integrated engineering, technology and processes may have a profound impact on the workforce over the next decade.

Mechatronics requires an evolution from unskilled to skilled labor in many industry and manufacturing environments. In fact, some argue that the demand for
technicians trained and skilled in these new areas of electronic control is in excess of the demand for basic mechanical skills (Coyle, 2006). *This trend toward multi-craft represents an opportunity; however, if we fail to act, Texas risks missing a great economic and technological wave which is transforming the nature of work from unskilled to skilled labor and technical education from what was once considered trade and vocational to highly advanced career and technical education.*

Specific requests for mechatronic technicians are posted quite commonly by European and Asian employers, especially German employers. *This can largely be attributed to the fact that, in Asia and Europe, mechatronics is often a government mandated program of education that produces graduates with well-defined skills (Halbern, 2006).* Employers in these countries understand the technical competencies of students who have graduated from such programs. This points to a challenge for students and administrators of mechatronic programs in the United States; graduates must be able to communicate to employers the specific multi-craft skills they have mastered. This is similar to the challenge that “software engineers” faced. This challenge was a major impetus for the development of IT certification standards that validated the knowledge of individuals within specific IT skills such as Oracle database administration or Cisco networking.

The field of mechatronics is wide and deep but integrative. It can mean many things to different people. Colleges must prepare graduates who can adequately define their differentiated multi-craft skills to potential employers.
**Derek Black, ARM Automation**

Graduates of these mechatronic programs must be able to communicate to employers the tasks that they are capable of performing. Can the graduate read a schematic? What real world problems have they solved? Have they ever had to reprogram a programmable logic controller? I would expect that graduates of these programs would be able to explain to me a specific problem they have solved and how they went about solving it. I am looking for a technician who has the capacity to understand troubleshooting across multiple disciplines not just repeat rote procedures.

**Job Responsibilities**

Mechatronics technicians will be responsible for supporting the installation, maintenance, repair, calibration and troubleshooting of mechatronics-related equipment. Their responsibilities will include routine and preventive maintenance, monitoring the performance of equipment and diagnosing and correcting problems according to operational procedures. Survey respondents indicated that the primary responsibility of mechatronic technicians would be the repair (74%) and maintenance (71%) of equipment. With the possible exception of design, mechatronic technicians are integral to maximizing the productive use of mechatronic equipment over its entire life cycle, including production, use and maintenance.

**Exhibit 3.2. Survey Question: What Would These Technicians’ Primary Duties Involve?**

<table>
<thead>
<tr>
<th>Task</th>
<th>Primary</th>
<th>Secondary</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair</td>
<td>74%</td>
<td>23%</td>
<td>3%</td>
</tr>
<tr>
<td>Maintenance</td>
<td>71%</td>
<td>26%</td>
<td>3%</td>
</tr>
<tr>
<td>Calibration</td>
<td>66%</td>
<td>31%</td>
<td>3%</td>
</tr>
<tr>
<td>Installation</td>
<td>59%</td>
<td>31%</td>
<td>9%</td>
</tr>
<tr>
<td>Retrofitting</td>
<td>39%</td>
<td>58%</td>
<td>3%</td>
</tr>
<tr>
<td>Other</td>
<td>40%</td>
<td>20%</td>
<td>40%</td>
</tr>
<tr>
<td>Design</td>
<td>14%</td>
<td>46%</td>
<td>39%</td>
</tr>
</tbody>
</table>
Employment Opportunities

Current Demand

As indicated in Exhibit 3.3, nearly 80 percent of survey respondents see significant value in graduates with formal mechatronic training. Such training reduces the cost and time needed to train technicians in the required skills and it minimizes the risk of hiring employees not prepared for multidisciplinary training. Nearly 80 percent of survey respondents indicated that formal training would reduce the time to acquire skills to be a productive mechatronic technician.

Exhibit 3.3. Survey Question: Formal Mechatronics Training Can Materially Decrease the Time Necessary to Gain the Skills Required for Successful Mechatronics Employment

The need for technicians broadly and holistically trained in mechatronics appears to be widespread. Directors of mechatronic programs in California, Kentucky and Minnesota indicate that graduates of their programs and other comparable multidisciplinary programs, such as robotics and advanced manufacturing, have almost all been hired on or even before graduation.

Ken Ryan, Director of the Mechatronics Program, Alexandria Technical College

The Alexandria mechatronic program has a 100% placement rate. Automation techs typically make $40,000 right out of school.

William Thompson, Vice President of Student Learning, Texas State Technical College West Texas

Our automation/robotics program has had a 100% placement rate since 1988. The average starting salary of graduates is around $35,000 to $40,000. In the last year, we had eight graduates who were hired on at $65,000. The problem is getting students into the program. There is no trouble placing students.
Eighty percent of survey respondents indicated they would hire at least one mechatronics-related technician within the next one to three years and 70 percent would hire at least one in the next year. By the most conservative estimate, the respondent companies alone will require 230 mechatronic technicians in the next 12 months and will require over 400 mechatronic technicians in the next one to three years. Five respondent companies indicated that they would hire at least 50 mechatronics-related technicians in the next three years. Three of these companies were semiconductor manufacturers.

**Exhibit 3.4. Survey Question: Anticipated New Mechatronics Hires in the Next 12 Months**

<table>
<thead>
<tr>
<th>Number of New Hires in Next 12 Months</th>
<th>Respondents</th>
<th>Percent of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>10</td>
<td>26%</td>
</tr>
<tr>
<td>1–3</td>
<td>14</td>
<td>36%</td>
</tr>
<tr>
<td>4–6</td>
<td>7</td>
<td>18%</td>
</tr>
<tr>
<td>7–15</td>
<td>4</td>
<td>10%</td>
</tr>
<tr>
<td>16–25</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>26–50</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>More than 50</td>
<td>3</td>
<td>8%</td>
</tr>
</tbody>
</table>

Number of respondents 39 100%

**Exhibit 3.5. Survey Question: Anticipated New Mechatronics Hires in the Next One to Three Years**

<table>
<thead>
<tr>
<th>Number of New Hires in Next 1–3 Years</th>
<th>Respondents</th>
<th>Percent of Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>7</td>
<td>18%</td>
</tr>
<tr>
<td>1–3</td>
<td>11</td>
<td>28%</td>
</tr>
<tr>
<td>4–6</td>
<td>8</td>
<td>21%</td>
</tr>
<tr>
<td>7–15</td>
<td>2</td>
<td>5%</td>
</tr>
<tr>
<td>16–25</td>
<td>5</td>
<td>13%</td>
</tr>
<tr>
<td>26–50</td>
<td>1</td>
<td>3%</td>
</tr>
<tr>
<td>More than 50</td>
<td>5</td>
<td>13%</td>
</tr>
</tbody>
</table>

Number of respondents 39 100%
Exhibit 3.6. Average Mechatronics Technician Entry-Level Salary at Companies Hiring More Than 50 Mechatronics-Related Technicians in Next One to Three Years

<table>
<thead>
<tr>
<th>Name of Company</th>
<th>Number of Employees</th>
<th>Average Entry-Level Starting Salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>1,001–10,000</td>
<td>$30,000–$35,000</td>
</tr>
<tr>
<td>Advanced Micro Devices*</td>
<td>More than 10,000</td>
<td>$45,000–$55,000</td>
</tr>
<tr>
<td>Tokyo Electron</td>
<td>1,001–10,000</td>
<td>$35,000–$45,000</td>
</tr>
<tr>
<td>Lower Colorado River Authority</td>
<td>1,001–10,000</td>
<td>$30,000–$35,000</td>
</tr>
<tr>
<td>Johnson Controls</td>
<td>More than 10,000</td>
<td>$30,000–$35,000</td>
</tr>
</tbody>
</table>

* AMD’s Worldwide Employment Figures

**Salaries**

Exhibit 3.6 shows entry-level salaries for mechatronics-related technicians among respondents who indicated they would hire more than 50 such positions in the next one to three years. Salaries range between $30,000 and $55,000.

These salary ranges are comparable to available labor market information for mechatronics-related Standard Occupational Categories (SOCs) that describe technicians in the separate disciplines that comprise mechatronics. Exhibit 3.7 presents salary and total employment data for these SOCs in the state of Texas as compiled by the Texas Workforce Commission. Entry-level salaries for these SOCs are in the $30,000 to $40,000 range. The salaries for experienced technicians increase to about $45,000 to $55,000 and above. This data corresponds well to the results of the survey. Seventy-three percent of survey respondents indicated that the entry-level starting salary for mechatronics-related technicians would be in the $30,000 to $45,000 range. Sixty-one percent indicated that the salary for employees with five years of experience would be in excess of $45,000 and none reported average salaries less than $30,000. According to the survey data, the average entry-level mechatronic technician salary is $34,230 and average salary after five years is $47,727, which amounts to a nearly seven percent increase in pay per year.

Exhibit 3.7. Texas Statewide Wages, Occupational Employment Statistics Program, 2005

<table>
<thead>
<tr>
<th>Standard Occupational Code</th>
<th>Standard Occupational Title</th>
<th>Estimated Employment</th>
<th>Avg. Hourly Wage</th>
<th>Entry Wage (hr)</th>
<th>Experienced Wage (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17–3024</td>
<td>Electro-Mechanical Technicians</td>
<td>1,220</td>
<td>$23.50 ($48,878)</td>
<td>$15.95 ($33,168)</td>
<td>$27.28 ($56,733)</td>
</tr>
<tr>
<td>17–3027</td>
<td>Mechanical Engineering Technicians</td>
<td>3,760</td>
<td>$25.59 ($53,231)</td>
<td>$17.23 ($35,831)</td>
<td>$29.77 ($61,930)</td>
</tr>
<tr>
<td>17–3023</td>
<td>Electrical and Electronic Engineering Technicians</td>
<td>15,790</td>
<td>$25.07 ($52,145)</td>
<td>$16.72 ($34,786)</td>
<td>$29.24 ($60,825)</td>
</tr>
<tr>
<td>49–9012</td>
<td>Control and Valve Installers and Repairers, Except Mechanical Door</td>
<td>5,670</td>
<td>$17.97 ($37,378)</td>
<td>$11.19 ($23,275)</td>
<td>$21.36 ($44,428)</td>
</tr>
<tr>
<td>Code</td>
<td>Occupation</td>
<td>Employment</td>
<td>Entry Level</td>
<td>After 5 Years</td>
<td>After 10 Years</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------</td>
<td>------------</td>
<td>-------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>49–2011</td>
<td>Computer, Automated Teller and Office Machine Repairers</td>
<td>14,350</td>
<td>$16.57 ($34,466)</td>
<td>$10.59 ($22,027)</td>
<td>$19.56 ($40,685)</td>
</tr>
<tr>
<td>49–9041</td>
<td>Industrial Machinery Mechanics</td>
<td>20,840</td>
<td>$18.69 ($38,875)</td>
<td>$11.98 ($24,918)</td>
<td>$22.05 ($45,864)</td>
</tr>
<tr>
<td>49–2094</td>
<td>Electrical and Electronics Repairers, Commercial and Industrial Equipment</td>
<td>6,540</td>
<td>$20.87 ($43,410)</td>
<td>$13.83 ($28,766)</td>
<td>$24.39 ($50,731)</td>
</tr>
<tr>
<td>49–2095</td>
<td>Electrical and Electronics Repairers, Powerhouse, Substation and Relay</td>
<td>1,270</td>
<td>$26.01 ($54,101)</td>
<td>$19.38 ($40,310)</td>
<td>$29.32 ($60,986)</td>
</tr>
</tbody>
</table>

Source: Labor Market & Career Information Department, Texas Workforce Commission (TRACER)

Exhibit 3.8. Survey Question: Average Mechatronics Technician Entry-Level Starting Salary

Exhibit 3.9. Survey Question: Average Mechatronics Technician Salary after Five Years
Exhibit 3.10 shows labor market information from the Texas Occupational and Skill Computer-Assisted Researcher database. Based on this data, 2,058 job openings will be created in mechatronics-related SOCs each year through 2012. Of these, 64% (1,331) will come from the replacement of existing workers. This data represents the impending workforce attrition shortage facing the advanced manufacturing sector. Based on these data, in the next three years Texas will have to produce nearly 2,200 technicians for mechatronic-related fields to meet expected employer demand by 2012.

**Exhibit 3.10. Mechatronics Labor Market Information from the Texas Occupational and Skill Computer-Assisted Researcher**

<table>
<thead>
<tr>
<th>SOC</th>
<th>Title</th>
<th>Texas Empl. 2002</th>
<th>Texas Empl. 2012</th>
<th>Absolute Change 2002–2012</th>
<th>Percent Change, 2002–2012</th>
<th>Average Openings per year due to replacement (Socrates)</th>
<th>Average Openings per year due to growth (Socrates)</th>
<th>Total Openings per year from growth and replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>17–3024</td>
<td>Electro-Mechanical Technicians</td>
<td>1,450</td>
<td>1,600</td>
<td>150</td>
<td>10.34%</td>
<td>31</td>
<td>15</td>
<td>46</td>
</tr>
<tr>
<td>17–3027</td>
<td>Mechanical Engineering Technicians</td>
<td>3,050</td>
<td>3,250</td>
<td>200</td>
<td>6.56%</td>
<td>64</td>
<td>19</td>
<td>83</td>
</tr>
<tr>
<td>17–3023</td>
<td>Electrical and Electronic Engineering Technicians</td>
<td>14,600</td>
<td>16,000</td>
<td>1,400</td>
<td>9.59%</td>
<td>306</td>
<td>142</td>
<td>448</td>
</tr>
<tr>
<td>49–9012</td>
<td>Control and Valve Installers and Repairers, Except Mechanical Door</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>49–2011</td>
<td>Computer, Automated Teller and Office Machine Repairers</td>
<td>13,850</td>
<td>15,200</td>
<td>1,350</td>
<td>9.75%</td>
<td>169</td>
<td>132</td>
<td>201</td>
</tr>
<tr>
<td>49–9041</td>
<td>Industrial Machinery Mechanics</td>
<td>19,900</td>
<td>22,200</td>
<td>2,300</td>
<td>11.56%</td>
<td>401</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>49–2094</td>
<td>Electrical and Electronics Repairers, Commercial and Industrial Equipment</td>
<td>7,350</td>
<td>8,000</td>
<td>650</td>
<td>8.84%</td>
<td>161</td>
<td>63</td>
<td>324</td>
</tr>
<tr>
<td>49–2095</td>
<td>Electrical and Electronics Repairers, Powerhouse, Substation and Relay</td>
<td>1,400</td>
<td>1,400</td>
<td>0</td>
<td>0%</td>
<td>30</td>
<td>2</td>
<td>32</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1,331</strong></td>
<td><strong>727</strong></td>
<td><strong>2,058</strong></td>
</tr>
</tbody>
</table>

Source: Texas Occupational and Skill Computer-Assisted Researcher and SOCRATES
The Department of Labor, as part of the Community Based Job Training Grant initiative, is funding programs that link high school manufacturing programs (e.g., dual credit agreements, etc.) with community and technical college programs to address workforce needs in such fields as advanced manufacturing, including Computer Numerically Controlled (CNC) machining and mechatronics. The Department of Labor has stated that a driver for the creation of the program is the impending threat of a shortage of skilled workers due to retirement. The Tech Prep of the Rio Grande Valley, which includes Texas State Technical College Harlingen has successfully applied and received a $1M award as part of this program (http://www.harlingen.tstc.edu/techprep/docs/HS_AP.pdf). This program is discussed in further detail later in the report.

**Location of Workforce**

Analysis of the data obtained from the Texas Workforce Development Board (WDA) Wages, Occupational Employment Statistics Program, 2005, which tracks occupational wages and employment figures by region of the state, shows that employment opportunities for mechatronics-related technicians will be greater in large metropolitan areas such as Houston, Dallas/Fort Worth, Austin and San Antonio than in smaller cities and towns. The top 10 regions, by total estimated employment, are presented in Exhibit 3.11 for three representative SOCs.

**Exhibit 3.11. Regional Estimated Employment by SOC**

### Electromechanical Technicians

<table>
<thead>
<tr>
<th>Region</th>
<th>Regional Code (see map)</th>
<th>Entry-Level Wage (hr)</th>
<th>Estimated Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf Coast</td>
<td>28</td>
<td>$16.44 ($34,195)</td>
<td>360</td>
</tr>
<tr>
<td>Capital Area</td>
<td>14</td>
<td>$17.44 ($36,275)</td>
<td>210</td>
</tr>
<tr>
<td>Dallas</td>
<td>6</td>
<td>$16.86 ($35,069)</td>
<td>170</td>
</tr>
<tr>
<td>Tarrant</td>
<td>5</td>
<td>$13.92 ($28,954)</td>
<td>170</td>
</tr>
<tr>
<td>North Central Texas</td>
<td>4</td>
<td>$14.07 ($29,266)</td>
<td>110</td>
</tr>
<tr>
<td>Heart of Texas</td>
<td>13</td>
<td>$15.02 ($31,242)</td>
<td>40</td>
</tr>
<tr>
<td>Alamo</td>
<td>20</td>
<td>$15.00 ($31,200)</td>
<td>30</td>
</tr>
</tbody>
</table>

### Electrical and Electronic Engineering Technicians

<table>
<thead>
<tr>
<th>Region</th>
<th>Regional Code (see map)</th>
<th>Entry-Level Wage (hr)</th>
<th>Estimated Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf Coast</td>
<td>28</td>
<td>$18.21 ($37,877)</td>
<td>4230</td>
</tr>
<tr>
<td>Dallas</td>
<td>6</td>
<td>$18.87 ($39,250)</td>
<td>3700</td>
</tr>
<tr>
<td>Capital Area</td>
<td>14</td>
<td>$15.41 ($32,053)</td>
<td>1730</td>
</tr>
<tr>
<td>Tarrant</td>
<td>5</td>
<td>$17.65 ($36,712)</td>
<td>1550</td>
</tr>
<tr>
<td>Alamo</td>
<td>20</td>
<td>$14.38 ($29,910)</td>
<td>860</td>
</tr>
<tr>
<td>North Central Texas</td>
<td>4</td>
<td>$17.72 ($36,858)</td>
<td>850</td>
</tr>
<tr>
<td>East Texas</td>
<td>8</td>
<td>$14.75 ($30,680)</td>
<td>330</td>
</tr>
<tr>
<td>Coastal Bend</td>
<td>22</td>
<td>$14.07 ($29,266)</td>
<td>300</td>
</tr>
<tr>
<td>Central Texas</td>
<td>26</td>
<td>$18.88 ($39,270)</td>
<td>240</td>
</tr>
<tr>
<td>Rural Capital</td>
<td>15</td>
<td>$17.66 ($36,733)</td>
<td>210</td>
</tr>
</tbody>
</table>
Potential Employers

The application of mechatronics is wide-ranging and has significant applications in many industries, including those defined by the Governor’s Advanced Manufacturing Industry Cluster that includes semiconductor manufacturing, automotive manufacturing, Micro-Electro-Mechanical Systems (MEMS) and nanotechnology. Other industry clusters where mechatronics will have a significant impact include petroleum refining and chemical processing, biotechnology and life sciences, aerospace and defense and power generation and transmission. An illustrative company directory of mechatronic employers, by industry cluster, is provided in Appendix D. Many of these employers were either interviewed for this project or responded to the survey.

Engineers in several industries are using particularly advanced mechatronic applications such as industrial control/networking and automation to increase the efficiency of production processes and improve the performance of
products. However, companies often struggle to find multi-craft technicians with the aptitude and skills to install, maintain, calibrate and repair this equipment.

**Pat Alba, Chief Administrative Officer, Austin Energy**

The upcoming expected shortage of workers is a nationwide problem. Public power utilities have a lot of the baby boomers as employees and they are nearing retirement age. Most students who are studying electronics don’t seem to think about power technology or working for utility companies. As with most fields, we are looking to have a more educated workforce with our younger employees that have a handle on modern computerized technology and not just mechanics. (Cited in “Austin Energy Seeks to Stave Off Critical Employee Shortage,” Austin American-Statesman (July 9, 2006.)

Some state employers have taken proactive steps to close workforce skill gaps. For example, Toyota partnered with the Alamo Community College District (ACCD), using a $2.15 million grant from the Texas Workforce Commission, to custom train workers in many essential technical fields that are mechatronics-related, including robotics, electromechanical technology, fuel cells and computer numerically controlled machining for their new manufacturing plant in San Antonio. These skills, which are extremely important to Toyota, are being taught by ACCD. The partnership and the availability of a trained workforce, was one of the major reasons Toyota cited for choosing San Antonio for the plant.
Chapter Four: Initiating Mechatronics Programs in Texas Colleges

Demand for Formal Multidisciplinary Training

The traditional disciplines at the core of mechatronics include mechanical, electrical, electronic, electronics, control systems and computer (including software) systems. Some existing community and technical college programs, specifically robotics and electromechanical engineering, provide multidisciplinary training across these subjects. Many of these programs, however, lack a systemic curriculum because of departmental boundaries. For the most part, students in traditional academic programs and colleges are trained in a narrow range of these fundamental disciplines (i.e., exclusively in electrical systems or mechanical engineering technology).

The conversion of today’s college graduates and incumbent workers into technicians capable of serving in a mechatronic environment is mostly a function of On-the-Job Training (OJT) and apprenticeship programs, in addition to employer-sponsored specialized short courses and seminars. This adds cost, time and risk to the post-graduate technician and engineer preparation process.

Employers interviewed for this study repeatedly referred to practical “multi-craft” training and experience as essential elements of the success of skilled employees. However, even as important as practical experience is to the success of mechatronic technicians, the breadth of mechatronic subject matter makes it essential that these technicians receive systemic training in these subjects so they can better understand the interdependency of mechatronic component systems. Interviews of potential mechatronic employers and the responses of survey respondents verify that formal training is a critical component of becoming a mechatronic technician (see Exhibit 4.1). Although not the focus of this study, this same movement towards multidisciplinary education is also necessary in many university science, engineering and technology-focused programs.

Respondents to the survey rated the attractiveness of mechatronics-related technicians with an associate degree or certificate in mechatronics and three years of related experience significantly higher than mechatronics-related technicians with comparable experience but no formal training. This points to the belief of many employers that mechatronics is sophisticated enough that formal training is necessary in addition to experience. Additionally, the importance of experience and formal training to employers points to incumbent and dislocated workers as a prime recruiting target for mechatronic programs.
Exhibit 4.1. On a Scale of 10 (Highest) to 1 (Lowest), How Would You Rate the Employment Attractiveness of Potential Employees with the Following Qualifications?

<table>
<thead>
<tr>
<th>Capability</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>A person with <strong>three-years experience in a related field</strong> such as mechanics, electronics, robotics or controls with a <strong>two-year mechatronics Associate Degree</strong></td>
<td>8.6</td>
</tr>
<tr>
<td>A person with <strong>three-years experience in a related field</strong> such as mechanics, robotics, electronics or controls with a <strong>one-year mechatronics certificate</strong></td>
<td>7</td>
</tr>
<tr>
<td>A college graduate with a <strong>two-year Associate Degree in Mechatronics, but with no field experience</strong></td>
<td>6.46</td>
</tr>
<tr>
<td>A college graduate with a <strong>two-year Associate Degree in a field of study directly related to mechatronics</strong> such as robotics or electromechanical systems, but with <strong>no field experience</strong></td>
<td>6.26</td>
</tr>
<tr>
<td>A person with <strong>three-years experience in a related field</strong> such as mechanics, robotics, electronics or controls, but <strong>no specific mechatronics training</strong></td>
<td>6.14</td>
</tr>
<tr>
<td>A college graduate with a <strong>one-year Certificate in Mechatronics, but with no field experience</strong></td>
<td>5.2</td>
</tr>
<tr>
<td>A college graduate with a <strong>one-year Certificate in an area directly related to mechatronics</strong> such as robotics or electromechanical systems, but with <strong>no field experience</strong></td>
<td>5</td>
</tr>
</tbody>
</table>

Relationship of Mechatronics to Existing College Programs

The term “mechatronics” is widely recognized in some industries, but not commonly used in some others, where a variety of names, such as “automated manufacturing,” “integrated systems technology,” “multi-craft” and “electromechanical systems engineering” are used.

Irrespective of semantics, the multidisciplinary design and manufacturing of mechatronic systems is increasing and as such, there is an acute need for systemically trained technicians who can service and operate such systems. Colleges in the state already conduct programs that provide students with multi-craft technical training in many of the disciplines that make up mechatronics, but these programs tend to be taught as distinct programs. Exhibit 4.2 illustrates the relationship between existing traditional programs and the multidisciplinary nature of mechatronics.

Exhibit 4.2. Relationship of Mechatronics to Existing College Programs
The increasing importance of mechatronic skills is particularly evident in the way employers view the evolution of related labor markets. Exhibit 4.3 below illustrates that although about half the survey respondents had no opinion with respect to the impact of increased mechatronic employment on employment related fields, those respondents who did have a position clearly see mechatronics as an additional required skill set in addition to traditional technical fields. Approximately 40 percent of survey respondents do not view mechatronic technicians as displacing technicians in other more narrowly defined fields. Hence, we conclude employers require the integrative capacity of mechatronic technicians as well as the skill sets of specialists.

**Exhibit 4.3.** Increases and Decreases in Employment Caused by Mechatronics

![Bar Chart]

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>No opinion</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mechatronics Technical Competencies**

The range of technologies that could be taught in specific mechatronic programs will vary according to individual institutional resources and the needs of targeted employers. *Students will need to understand mechatronics broadly, however, an understanding of the interdependencies and relationships among mechatronic systems is essential.* Mechatronics systems are integrated rather than coupled; therefore, a systemic understanding is essential.

*Michael Sumner, Robotics and Automation, Holcim Corporation*

I know most of the training will focus on programmable logic controllers, robotics and electronics, but the training should include preventive maintenance related to fluid power systems and mechanical systems such as bearings, seals, gearboxes, etc. It should include predictive maintenance techniques and procedures because this would greatly increase the employability of anyone in the electromechanical field. The training should also include fabrication techniques such as pipefitting and some general welding.

Exhibit 4.4 provides a comparison of four existing mechatronic associate degree programs in the United States and the respective core topics addressed by each. A more complete description of the Texas State Technical College Harlingen program is provided in Chapter 5 along with descriptions of existing mechatronics programs.
Each of these programs encompasses an impressive range of topics and designing such programs within the time constraints of a two- to three-year degree program requires thoughtful instructional design considerations. Specifically, curriculum can be focused by internalizing targeted industry needs rather than trying to deal with all of the possible topics in mechatronics.

**Exhibit 4.4. Course Topics Addressed in Existing Two-Year Mechatronics Programs**

<table>
<thead>
<tr>
<th>Topic</th>
<th>TSTC Harlingen (TX)</th>
<th>Sierra College (CA)</th>
<th>Alexandria Technical College (MN)</th>
<th>St. Clair County Community College (MI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Manufacturing</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Blueprint/Schematic Reading</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>CNC Machine Maintenance</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CNC Machine Programming</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>CNC Machine Troubleshooting</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Computer Integrated Manufacturing (CIM)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Computer Programming (C, C++, etc.)</td>
<td></td>
<td></td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Computer-Aided Design (CAD)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Conventional Machining/Fabrication</td>
<td></td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Electric Motors</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electrical Instruments &amp; Measurements</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electrical Motor Control</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Electrical Wiring &amp; Installation</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electricity &amp; Electrical Systems (AC/DC)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electro-Fluid Power</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electronic Drives</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Electronics</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Fluid Power</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Foundational Mathematics</td>
<td>x</td>
<td>Pre-Requisite</td>
<td>Pre-Requisite</td>
<td>x</td>
</tr>
<tr>
<td>Foundational Science</td>
<td>x</td>
<td>Pre-Requisite</td>
<td>Pre-Requisite</td>
<td>x</td>
</tr>
<tr>
<td>Hydraulics</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Internetworking</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Introduction to Computers</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Lubrication</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Maintenance Practices</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Mechanical Drives</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Pneumatics</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Power Distribution</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Preventative Maintenance</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Programmable Logic Controllers</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Robotics</td>
<td></td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Semiconductor Electronics</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Servo Control</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>
Challenge of Holistically Integrating Several Traditional Disciplines

The authors found widespread concern that the learning experience of students participating in two-year mechatronic programs might be diluted because they must learn the fundamentals of multiple disciplines in the same amount of time typically allotted for learning one traditional discipline. A mechatronic curriculum must define new and modified courses that integrate essential Knowledge, Skills and Abilities (KSA) required by targeted industry employers rather than trying to teach all possible combinations of Mechatronics systems, theories and applications.

Michael Halbern, Director of the Mechatronics Program, Sierra College, California

Mechatronics requires a “just in time” approach to teaching learning objectives where students learn foundational subjects such as college algebra in the context of solving practical problems in their lab studies as opposed to a “just in case” approach where learning objectives are presented in the context of abstract problem solving. There is just not enough time to address foundational subjects within the structure of an isolated course.

The new mechatronic program at Texas State Technical College Harlingen includes foundational mathematics courses in college algebra and plane trigonometry, in addition to a math/natural science elective (Exhibit 5.1). Although the programs at Sierra and Alexandria Colleges do not include formal courses in these areas, directors of both programs have indicated that students must demonstrate proficiency in fundamental math and science before they are admitted to their programs.

Sam Nauman, Director of the Integrated Systems Technology lab at Texas State Technical College Harlingen, believes that with the use of hands-on, projects-based training, mechatronic principles can be properly taught within a two-year program. He points out that this is also the belief of industry partners, including General Motors and Caterpillar that helped develop the AMIST curriculum the college is using as the basis of its mechatronic program. Like Nauman, all of the mechatronic program coordinators and employers interviewed for this study emphasized that hands-on training on equipment that they will actually encounter in industry was essential to the success of a broad multidisciplinary program such as mechatronics.

Survey data of related Texas employers strongly support the idea that colleges play a critical role in helping employers meet their mechatronic workforce requirements. Nearly 95 percent of survey respondents indicated that they strongly agree or agree with the statement that “A properly designed and conducted two-year college mechatronic program can provide graduates with the skills required for successful employment as a mechatronic technician.”
Exhibit 4.5. A Properly Designed and Conducted Two-Year College Mechatronics Program Can Provide Graduates with the Skills Required for Successful Employment as a Mechatronics Technician

Knowledge, Skills and Abilities (KSAs)

Nick DeNardo, Tokyo Electron

For Tokyo Electron’s specific needs, it is the actual ability to accomplish work-related tasks that is more important than the theory that describes the technical functions that are being accomplished (practical versus theoretical). This is the difference between someone with an engineering technician’s degree and someone with an engineering degree. TEL hires people with engineering degrees mostly into design and research jobs. There is a need for mechatronic training at the practical or field engineering, level. These are the people who are actually troubleshooting and repairing equipment. For that job function, it is the application that is important. We have seen people who understood the concept of troubleshooting, but they can’t troubleshoot because they don’t know where to break a system down into modules and start looking for the faults.

Mechatronics technicians must possess a broad range of KSAs across multiple technologies and applications. Moreover, they must be capable of integrating this knowledge in a way that allows them to meet the needs of employers. The KSAs for such employment will include the following broad job related requirements:

- Read and troubleshoot from schematics, blueprints, ladder diagrams and physical layout drawings. This includes mechanical drawings, electrical circuit diagrams and pneumatic circuit diagrams.
- Update changes to schematics including changes to electrical, pneumatic, hydraulic and PLC drawings and schematics.
- Install, adjust and troubleshoot mechanical, electrical, electronic control and computer systems and components (programmable logic controllers).
• Measure, test and adjust mechanical, electrical, electronic control and computer components.

• Demonstrate computer and programming skills.

• Document technical data of work processes and work results.

• Develop and document planned preventative maintenance programs.

• Perform planned maintenance tasks.

• Document safety measures.

• Install and test safety measures to prevent damage to personnel and equipment.

• Demonstrate an awareness and ability to perform safety procedures when carrying out preventative maintenance tasks.

• Document data concerning machine and equipment failure and breakdown.

• Demonstrate multi-craft Knowledge, Skills and Abilities (KSAs)—especially problem solving, analysis and communication.

Special KSAs Required of Mechatronics Technicians

• The technologies that are used in an environment where mechatronic technicians are employed will likely undergo significant change rapidly. Therefore, mechatronic technicians must have the ability to continuously learn new skills throughout their careers.

• The ability to read schematics and blueprints and understand how a total system composed of various mechanical, electrical, control and computer components works together. These skills are critical to troubleshooting complex systems, especially older legacy systems without computer guided diagnostic tools. In other words, the mechatronic technician must be able to say to himself “Is the problem I am addressing an electrical problem, a mechanical problem or an electromechanical problem?” and then solve the problem.

• The ability to use computer guided monitoring/diagnostics/troubleshooting tools that are becoming more prevalent in industry. This relieves somewhat the requirement for fundamental skills. However, those who have these skills will be more valuable at times because a critical number of specialists will be required to handle exceptions that are not described in troubleshooting guides.

Integration with Skills beyond Mechatronics

In many industries, technician responsibilities extend beyond the range of mechatronics. For example, the semiconductor manufacturing industry used to segregate process and equipment technicians from manufacturing operators. Beginning in the early 1990s, however, industry leaders began creating
“manufacturing technicians.” These manufacturing technicians now routinely operate and maintain/repair their equipment in addition to executing the production process. They have responsibility not only for the productivity and economics of their portion of the overall manufacturing process, but also for the quality of results obtained. This trend is becoming pervasive in other manufacturing environments.

Mechatronics technicians will also find themselves increasingly involved in the continuous improvement process with regard to the equipment and processes over which they have responsibility.

**Essential SCAN Skills**

Obviously, mechatronic technicians must be technically competent, but a lack of common “soft” skills could prevent them from being optimally effective. Enhancing or cultivating soft skills during the course of a two-year program is essential. For example, mechatronic technicians will work with engineers and other technicians in group projects. It is therefore essential that they have good communication skills and be able to work collaboratively in solving problems. Good communication skills will be essential to the mechatronic technician in explaining technical issues to other technicians or supervisors that might involve technical problems outside of that person’s expertise. The mechatronic technician must be able to present technical issues clearly and unambiguously.

**Exhibit 4.6.** On a Scale of 10 (Highest) to 1 (Lowest), How Would You Rate the Importance of the Following Capabilities for Mechatronics Technicians?

<table>
<thead>
<tr>
<th>Capability</th>
<th>Average Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have a strong work ethic</td>
<td>9.38</td>
</tr>
<tr>
<td>Work efficiently, effectively and collaboratively as a member of a team</td>
<td>8.88</td>
</tr>
<tr>
<td>Work efficiently and effectively when working individually</td>
<td>8.62</td>
</tr>
<tr>
<td>Work, build, maintain and troubleshoot electronic and logic systems from schematics</td>
<td>8.29</td>
</tr>
<tr>
<td>Understand and appreciate complex systems</td>
<td>7.85</td>
</tr>
<tr>
<td>Troubleshoot down to the macro or module level</td>
<td>7.85</td>
</tr>
<tr>
<td>Communicate effectively in writing including preparation of reports</td>
<td>7.65</td>
</tr>
<tr>
<td>Effectively employ computer guided monitoring, diagnostic and troubleshooting systems to evaluate complex (mechatronic) systems</td>
<td>7.47</td>
</tr>
<tr>
<td>Participate in and contribute to continuous improvement activities</td>
<td>7.47</td>
</tr>
<tr>
<td>Analyze the effects of complex tool system interactions and variations</td>
<td>7.38</td>
</tr>
<tr>
<td>Exhibit highly creative and/or abstract thinking</td>
<td>7.15</td>
</tr>
<tr>
<td>Communicate effectively orally including formal and informal presentations</td>
<td>7.03</td>
</tr>
<tr>
<td>Monitor and maintain multivariate statistical process control (SPC) systems</td>
<td>5.88</td>
</tr>
</tbody>
</table>

**Qualified Faculty**

Colleges that already have strong existing programs in electrical systems, electronics technology, robotics and automation, computerized control systems (instrumentation), industrial maintenance and engineering, electromechanical engineering and
mechanical engineering are well positioned to develop mechatronic programs. However, even colleges with faculty in these disciplines will have to devote resources to restructing the teaching of mechatronics as an integrated whole with specific industry applications. There are a number of different ways that faculty can gain experience and training in this area: externships with mechatronic employers, fellowships at colleges with well-established mechatronic programs such as Sierra College in California, mechatronic faculty training programs offered at National Science Foundation (NSF) Advanced Technology Education Centers such as the California Regional Consortium for Engineering Advances in Technological Education (CREATE) or training programs offered through manufacturers such as Siemens, which has a formal mechatronic faculty training and certification program.

An additional difficulty colleges will encounter in retaining appropriate faculty is that mechatronic programs will require a unique course delivery style. This will involve the intensive compression and integration of subject matter with hands-on labs in a thoughtful and holistic fashion. The experience of faculty from existing mechatronic programs in developing such courses will be informative.

It is important that this faculty training be directly related to the mechatronic training needs of the college’s industry partners and customers. As Ken Ryan, director of the mechatronic program at Alexandria Technical College, pointed out, “the director of a mechatronic program can send members of their faculty to all of the Siemens training (i.e., programmable logic controllers) in the world, but it’s not a really effective use of resources if that college turns around and learns that 90% of the installation base in the region where its students are being placed is Allen Bradley.”

Off-the-Shelf Mechatronics Programs and Trainers

It is essential that colleges interested in establishing mechatronic programs provide students with laboratory facilities that enable hands-on experience. There are a number of options that colleges interested in establishing mechatronic programs can pursue to acquire suitable laboratory and training facilities. For example, students in the Alexandria program regularly work with automation hardware that is networked together in fully-integrated systems similar to those commonly employed in the packaging industry, a large part of the college’s service base. These systems are used to instruct students in pneumatics, the electronics of sensing and solenoid technologies. This hardware is controlled by programmable logic controllers, which have very sophisticated human/machine interfaces and are tied together by industrial networks.

According to Pat Hobbs, the Vice President of Student Learning at Texas State Technical College Harlingen, the cost of a one-cell laboratory trainer system used in their new mechatronic program is about $200,000. The trainer, which can be used...
by two students at a time, was developed by the Amatrol Corporation, a provider of skill based integrated technical learning systems in many mechatronics-related disciplines (www.amatrol.com). The Amatrol modules that the Harlingen program uses encompass training in hydraulics, pneumatics, mechanical drives, electrical wiring, PLCs, electronics and motor control systems. The cost of the trainers includes interactive multimedia as well as print-based student learning materials, instructor guides, industrial quality hands-on training equipment and faculty training. Amatrol now offers a broader range of mechatronics-related training systems and curriculum at different price-points.

In the past, technical programs at colleges have received donated equipment and supplies from local industry. Since some companies update equipment frequently because of technology advances, the equipment they donate can be very functional and useful for training purposes. Directors of the mechatronic programs at Sierra and Alexandria Technical College indicated that donated equipment and supplies from local employers was essential to establishing and maintaining their programs.

Exhibit 4.7. Mechatronics 860-Mini-Cim Mechatronics Trainer from Amatrol

Ken Ryan, Alexandria Technical College

Alexandria could have never created a lab as technically advanced as the one we have now if we had tried to do it under the normal budgetary processes of the State of Minnesota. We have purchased some equipment with third party grant monies from the National Science Foundation and the Society of Manufacturing Engineers, however most of the equipment has come from leveraging our relationships with industry.

Other approaches to securing adequate training facilities include tailoring programs so that students can utilize existing laboratories at other campuses through One-plus-One articulation agreements (i.e., Career Foundation Model), conversion of existing laboratories (e.g., electronics technology labs) to make them suitable for mechatronic
training and even Web-based virtual training that augments physical lab facilities. Owens College in Ohio has an online mechatronic degree course, developed by Amatrol, based on the AMIST materials that Texas State Technical College Harlingen also uses. The “virtual” equipment used in the course has the same look and feel of equipment used in the AMIST lab. Virtual trainers can also be useful for distance training and continuing education for technicians already in the workforce.

Lab-Volt’s Flexible Manufacturing System is another example of a modern mechatronics trainer that integrates Programmable Logic Controllers (PLCs), electrical and mechanical actuators, motion control systems, sensors, vision systems, bar coding and numerous advanced interfacing techniques.

Exhibit 4.8. Mechatronics — Flexible Manufacturing System Trainer from Lab-Volt

Colleges considering mechatronic programs may also use Internet-based virtual training modules and PC-based simulations to augment physical lab facilities. Amatrol and Lab-Volt have developed virtual learning systems that are available in addition to the printed curriculum materials that accompany their trainers. The virtual versions of the training materials have the same content as the printed versions, plus they include 3D simulations and interactive activities that have the same look and feel of the physical trainers.

Virtualizations, simulations and video game-based techniques should be considered in addition to traditional web and distance training methods. Continuing education outreach and market development with virtual classrooms (and simulations) should be considered for technicians in the workforce who want to upgrade from legacy systems to mechatronics technicians.

Another option to support mechatronics education is the use of an introductory robotics platform such as Qwerk from Austin-based Charmedlabs.com. Developed in collaboration with the Mobile Robot Programming Lab at Carnegie Mellon
University’s Robotics Institute, this robot is a second generation of the Personal Rover and was developed to “catalyze creativity, foster technological empowerment and inspire learning by transforming robotics into an accessible and collaborative tool for exploration.” When Qwerk is combined with CMU’s TeRK free software, a powerful and affordable mechatronics introductory platform is available for $349. When QERK hardware is combined with TeRK software and “robot recipes” from www.terk.ri.cmu.edu one can build a Telepresence Robot for $550.

**Exhibit 4.9. Qwerk and TeRK Robot for Education**

Additional resources for college and secondary education include kits and competitions such as World Skills International Mechatronics Olympics, SkillsUSA, US For Inspiration and Recognition of Science and Technology (US FIRST), BotBall, BEST, Engineering And Robotics Learned Young (EARLY), Science Olympiad, Project Lead the Way, Micro Mouse, fischertechnik, TERK, QWERK, and Hobby Engineering. See Appendix E for more information on these and other related educational programs.

**Importance of “Hands-on” Training for Mechatronics**

Entry-level technicians who graduate from a mechatronic program will enter the workforce better prepared to meet the demands of employers who need multi-craft technicians. However, no amount of education, including lab work, will eliminate the need for hands-on and inquiry-based learning where theory and general knowledge are applied and adapted in real-world contexts. Thus, employers interviewed for this study emphasize the importance of giving students “real-world,” industry-related experiences during the course of their education. Along with student internships and co-ops, employers interviewed made several suggestions concerning how students may obtain such experience.
1) **Colleges can work cooperatively with industry on projects.** There are companies that often need small mechatronics-related projects completed that are solvable with the resources, both capital and intellectual, available within a college environment. Students complete most of the work on the projects with faculty leadership. In addition to their educational value, these projects also give students a tangible way of describing technical problems that they have solved to potential employers. Valuable team building and communication skills are developed as students interact with other team members, the faculty sponsor and industry. An example of this kind of cooperation recently occurred between the snowmobile manufacturer Arctic Cat and the mechatronic program at Alexandria Technical College. According to Ken Ryan, director of the program, Arctic was commissioning an entirely new engine assembly line in a Minnesota city near the college. Arctic wanted to include automated vision inspection systems on the assembly lines to verify that parts were properly installed on the engines. The company asked Alexandria to help choose a vision system and provide guidance regarding its use. Developing the specifications for the system became a student project that was valuable: it provided students with experience in how to approach and solve actual industry problems and it also gave students, indeed the entire program, a way of directly demonstrating their value to a local industry partner/potential employer.

2) **Capstone courses that require students to solve a problem whose solution requires the application of many of the skills from multiple disciplines.** Students in the Sierra College mechatronic program take a Capstone course that requires them to design and build a mechatronic device that includes a microcontroller. In the past, students have built a variety of devices including an automated feeding system for pets and an irrigation control system. Capstone projects provide students with a tangible product that they can demonstrate and discuss with potential employers. The projects also give students a means of demonstrating their interpersonal skills to employers because they have the ability to conduct a meaningful technical conversation.

3) **Skills based competitions such as the World Skills International Mechatronics “Olympics”, SkillsUSA, US FIRST, Botball, Early and BEST.** See Appendix E for more details on these programs.

**Student Interest**

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**Dave James, Samsung**

Employers, including Samsung, often have trouble finding skilled labor for positions such as sheet metal workers and millwrights. The state must find a way to attract more students into manufacturing-related college programs. It is crucial for Texas industry to demonstrate to K-12 students and their primary influencers, the parents, that the manufacturing sector offers attractive career choices.

Representatives from a broad range of industry sectors have indicated that there is a shortage of skilled entry-level technicians graduating from two-year technical programs. This problem is expected to become increasingly acute as manufacturing technicians in the baby boom
generation reach retirement age and a lack of qualified techs to fill their positions grows. A number of entities have recognized this problem and moved to correct it. For example, Austin Community College has partnered with Austin Energy to recruit and train workers, many of whom are effectively mechatronic technicians, to fill a critical workforce gap that will emerge in the next few years. Austin Energy expects 22% of their workforce, 310 of the 1,429 employees, to retire within the next five years (Van-Orta, 2006).

Additionally, the Department of Labor, as part of the Community Based Job Training Grant that Texas State Technical College Harlingen received to construct its IST lab, is funding the Tech Prep of the Rio Grande Valley. A major component of the organization's mission is to strengthen programs that link high school manufacturing programs (e.g., dual credit agreements, etc.) with Texas State Technical College Harlingen programs that address advanced manufacturing, including Computer Numerically Controlled (CNC) machining and mechatronics. A major driver for the creation of the program is the impending threat of a shortage of skilled workers due to retirement (www.harlingen.tstc.edu/techprep/docs/HS_AP.pdf).

College program directors in areas such as robotics and automation indicate that they have no problem placing graduates in high-paying positions (at least $35,000 per year). The problem they face is attracting students to the program and graduating students for hire. A significant part of the problem is that students and their primary influencers, their parents, are often misinformed about career opportunities in manufacturing. News reports about plant closings and the outsourcing of jobs to other countries such as China have convinced many that job opportunities in the manufacturing sector are shrinking. This misperception must be addressed by industry, colleges and the state’s political and economic development leadership if the number of students pursuing advanced technical and manufacturing careers is going to be increased. Awareness about the opportunities for technicians trained in mechatronics-related subjects must be developed in early education.

Some colleges are having early success using mobile trainers, simulations and distance learning to connect to students at K-12 schools in Texas and demonstrate mechatronics/advanced manufacturing through interactive, hands-on examples.

Programs such as World Skills International Mechatronics Olympics, SkillsUSA, US For Inspiration and Recognition of Science and Technology (US FIRST), BotBall, BEST and and Engineering And Robotics Learned Young (EARLY) are also excellent tools to increase awareness about mechatronics among the high school population. See Appendix E for more examples of K-12 mechatronics programs.

**Will Thompson, TSTC West Texas**

Two of the largest employers of graduates of our Electronics Technology program have stepped forward and agreed to hire two recruiters for the program. They are interested in increasing the number of students who enter and graduate from the program. They have agreed to pay the recruiters' salaries for three years.
Retraining Incumbent and Dislocated Workers

Many dislocated and incumbent manufacturing workers are at-risk. Their skills have become outdated and obsolete as a result of technical developments, including the increasing use of information technology based tools, such as PLCs, in the manufacturing environment. Therefore, it is highly desirable for colleges planning mechatronic programs to provide training for this group of potential students. Students with such training are especially attractive to employers because they already possess industry experience that many traditional students lack.

Approaches to reaching such students include evening and weekend classes and online and distance learning courses. The use of virtual collaboration and simulation in both on-site and distance learning activities would provide a modern approach to the learning challenge. The mechatronic program at Texas State Technical College Harlingen plans to eventually use all of these approaches to provide training for dislocated and incumbent workers in the Valley region (Nauman, 2006).

Partnerships with industry will be important in attracting incumbent workers. In addition to subsidizing or paying the tuition of students, industry partners will often donate equipment to the programs that can be used to augment training opportunities for students.

Thoughts on Mechatronics Program Initiation

The initiation of a two-year program that can train students to an appropriate depth across the broad range of disciplines that mechatronics entails is a costly endeavor in terms of both time and money. Colleges considering the initiation of such programs must have the support of a broad range of stakeholders in their service base. These include:

- Employers that are expected to hire graduates of the program.
- Faculty and program chairs within the college that will have to share resources or integrate programs (i.e., classes, lab facilities, students and most importantly, their time) to make the multidisciplinary program successful.
- The community at large, including the K-12 establishment, which will educate and steer potential students and their parents, toward the program and its opportunities.

Considering the investment such programs represent, colleges may want to develop new mechatronic programs incrementally. Using this approach, colleges would not immediately establish an entirely integrated mechatronic curriculum. Instead, the process of establishing a program would be accomplished by “poking holes” in silo walls between existing programs. In this approach, students in existing programs can take courses in other programs where they can gain skills applicable to their training as multi-craft technicians. For example, a mechanical engineering technology program interested in teaching its students the fundamentals of industrial networking can send its students to a course taught by the computer networking and systems administration program. Over time, the industrial networking course would work its way back into
the mechanical engineering technology programs as a distinct class because there are aspects of industrial networking that are unique from the voice and data networking issues taught in traditional network systems programs. Over time, this approach can be used to develop a number of multidisciplinary courses. Eventually, a fully integrated mechatronic program can be created.

Finally, a subject that spans as many disciplines as mechatronics will have multiple meanings to different people. Therefore, it is essential that colleges establishing such programs work closely with employers and regional workforce boards to define the specific KSAs that are needed by industry partners. For example, a mechatronic program in the Austin region will probably place special instructional emphasis on mechatronic topics of interest to semiconductor manufacturers, such as statistical process control. A program in Houston might place an emphasis on subjects of interest to the oil and chemical refining industries. Each college must create programs that emphasize the transfer of specific KSAs that are of interest to their local industry base and can be adequately taught with the resources available at the college.
Chapter Five: Mechatronics Curriculum Resources

This chapter provides useful resources and models for colleges interested in developing mechatronics programs. Perhaps most useful is an overview of existing mechatronic degree programs around the country. Texas State Technical College Harlingen’s new mechatronic AAS program and six-year curriculum plan will be particularly useful resources that Texas colleges can leverage to develop their own mechatronic programs. The chapter concludes with an overview of government and trade associations for further guidance and potential funding sources.

Existing Mechatronic Programs

The information provided below was gathered from personal interviews with the directors of existing mechatronic programs and other college authorities, as well as an examination of college publications that provided information about course content and curriculum structure. The names of the people interviewed, together with contact information, is present in each section.

Texas State Technical College Harlingen Mechatronics Program

Texas State Technical College Harlingen received a $1 million grant from the National Center for Integrated Systems Technology (NCIST) to establish an Advanced Manufacturing/Integrated Systems Technology Laboratory (AMIST). In addition to providing career and technical training for incumbent and dislocated workers, and based on earlier research conducted by TSTC Emerging Technologies, TSTC Harlingen launched the first Texas mechatronic degree program in September 2006. The Associate of Applied Science (AAS) mechatronics degree program was developed by updating and transitioning existing programs such as electromechanical and electronics engineering, that were experiencing low enrollments, into the new integrated mechatronics program. The college selected mechatronics as the best name for the new program because it most accurately described the multidisciplinary curriculum planned in conjunction with new laboratory.

In providing the NCIST grant, the federal government specified three goals for the college:

- To train dislocated workers from industries that lost jobs due to international competition and the movement of these jobs to overseas locations such as Latin America, The Middle East, Far East and Southeast Asia. The workforce training being offered in these labs consists of 272 contact hours (12 credit hours or 27.2 CEUs) and prepares these workers for new, more highly skilled jobs.

- To bring the skills of incumbent workers up to date and more competitive in the marketplace. These employees are more likely to keep their jobs and attain promotions because of their enhanced skills.
• To develop an Associate degree plan that incorporates all of the elements taught in the AMIST training curriculum, including an electrical maintenance course, programmable logic controller course, mechanical systems maintenance course and a fluid power specialist course. Combined, intelligent mechanical systems or “mechatronics.”

The curriculum for the mechatronic degree program (Exhibit 5.1) is based on an existing and now renamed Electrical-Mechanical Manufacturing Technology degree curriculum. Ultimately, that curriculum will be updated and broadened with AMIST curriculum materials developed by the Department of Labor in conjunction with a number of manufacturing entities including General Motors and Caterpillar. This broadening will include the inclusion of courses in subject areas such as robotics, laser visioning systems, digital electronics, advanced manufacturing, integrated systems and instrumentation. This program is a model program that exemplifies the way ahead for colleges who want to reorganize the teaching of science, engineering and technology around common principles. The program offers general mechatronic training in technical areas that mechatronic technicians will encounter in a wide range of production environments. These graduates will be well prepared for specialized training by their employers.

**Current Status**

The Higher Education Coordinating Board approved the name change to mechatronics and the program began accepting students in the fall of 2006. The existing courses already have Workforce Education Course Model (WECM) approval. Students currently seeking Electrical-Mechanical Manufacturing Technology degrees or certificates will be transitioned to the new mechatronic program. That program typically has 40 students at any one time.

**Employment Opportunities**

According to Pat Hobbs, Vice President of Student Learning at Texas State Technical College Harlingen, in the past, the majority of the college’s highly skilled graduates have left the Valley upon graduation. This was largely due to the fact that the only large, high paying industry in the region is health care. However, the college believes that attractive employment for graduates of the mechatronic program can be created in the region with the support of the local manufacturers association and the Texas Workforce Commission.

To satisfy the NCIST goal of training dislocated workers, the college has conducted training for incumbent and displaced workers and believes that the relationships being built through this training will pay off in the increased demand for its graduates. The college is confident that the 272 hours of concentrated training that is being conducted within the lab will produce graduates capable of filling technician positions at Toyota’s new manufacturing plant in San Antonio. In fact, Toyota recently hired a student who was trained in the college’s NCIST lab. The college expects graduates of the mechatronic program to earn between $14 to $20 per hour.
Laboratory Facilities

The AMIST laboratory (Exhibit 4.8) at Texas State Technical College Harlingen is not large. It contains five individual versions (or “cells”) of each of the required laboratory trainers. The lab can hold 10 or 12 students at one time, but through creative scheduling arrangements, the program is staggering course offerings and running several cohorts through the lab each semester. Each cell costs $200,000.

Pat Hobbs, Vice President for Student Learning, Texas State Technical College Harlingen

A major problem for other colleges initiating mechatronic programs will be the cost of laboratory facilities. These are high investment programs and not every college should try to create one. To get around this problem, colleges might offer technical courses without a lab component, but it is difficult to see how a student can be effectively trained in this area unless they know how to actually operate, maintain and calibrate the equipment. A possible solution is that mechatronic programs could be established on a regional basis. In such a system, students would complete their basic coursework at a “home” college and then transfer to a regional Texas State Technical College campus with an NCIST lab to complete their lab/technical courses.

Exhibit 5.1. Mechatronics Curriculum, TSTC Harlingen

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<tr>
<td>ELMT 1305</td>
<td>Basic Fluid Power</td>
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<tr>
<td>ELMT 2370</td>
<td>Final Project</td>
<td>3</td>
</tr>
<tr>
<td>SPCH 1318</td>
<td>Interpersonal Communication</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Humanities/Fine Arts Elective</td>
<td>3</td>
</tr>
<tr>
<td>ELMT 2339</td>
<td>Advanced Programmable Logic Controller</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Semester Total</td>
<td>12</td>
</tr>
</tbody>
</table>

All of these courses are included in the Workforce Education Course Manual (WECM).

**Alexandria Technical College**

The Alexandria Technical College (ATC) Center for Automation and Motion Control (www.camc-online.org) was established in 1988. The college serves a cluster of advanced high-speed, automated packaging companies in Minnesota. This includes a number of Fortune 500 companies including food and beverage manufacturers, pharmaceutical companies, medical device companies and the companies that actually manufacture the packaging equipment. In the Twin Cities region, Boston Scientific and Medtronics, medical device manufacturers, are major employers of students who graduate from the program.

**Program Description**

Although it is not formally named mechatronics, the CAMC program covers a number of subjects that are central to the core of mechatronics: programmable logic controllers, industrial networking, motion control, advanced machine vision.

As part of its mechatronic program, ATC provides customized training to industrial partners through a separate business unit within the college. These partners often send incumbent workers to ATC for continuing education in mechatronics-related subjects. A significant portion of this training is funded by the state of Minnesota and a portion of it is funded by the companies themselves. The mechatronic labs that are used for this industrial training are the same ones that Alexandria uses to train its traditional day students.
Current Status

Current enrollment in the ATC mechatronic program is down from previous years. The program graduated 22 students in the 2005-2006 school year and is on track to enroll 28 to 32 students in fall 2006. However, as recently as 2000, the program enrolled 70 students each semester.

Recently, ATC obtained a $207,000 grant from the SME MEP program to form the Minnesota Center for Advanced Manufacturing Automation. Although the Center does not include the term mechatronics in its name, its mission addresses the relevant subject areas including mechanical, electrical, programming and network technology for automation. The Center is a pilot project that is being used to develop information, trainers and curriculum for Minnesota high schools in the area of mechatronics.

Employment Opportunities

According to Ken Ryan, director of the ATC program, the college has a 100 percent placement rate. Starting salaries for graduates who seek employment at packaging OEMs in Alexandria’s immediate vicinity are $23,000 to $27,000. After five years of experience, student salaries typically increase to $33,000 to $37,000. Students who start their careers as automation technicians often go to work for one of the medical device manufacturers in the Twin Cities where starting salaries may reach $45,000.

Relations with Industry

Since its beginning, ATC has maintained close relationships with local industries. The college has a very active industry advisory committee. This committee brings its mechatronics needs to the attention of the program and the program works to integrate teachings related to those subjects into the curriculum. For example, automated packaging machine manufacturers that are members of this group asked ATC for additional emphasis in safety because of customer requests for machines with intrinsic safety. ATC responded to this request by incorporating more safety training into the program.

Another way that ATC maintains close contact with industry is through their lab. The region has a large number of packaging OEMs that build packaging machines. There are also a large number of technology providers that provide services and products to OEMs. Moreover, the OEMs are constantly looking for end users such as large food and beverage manufacturers to purchase their packaging machinery. All of these groups either send their employees to ATC’s labs for continuing education or supply equipment to the labs so that employees of their potential customers can actually see it in operation. This is an excellent strategy that may be used to acquire expensive equipment—have the manufacturer grant terms for the use of advanced machinery for students while allowing industry to attending training classes on campus and bring customers on campus to demonstrate products in use.
Laboratory Facilities utilize the equipment for customer tours which increases the visibility of the college

Although some of the laboratory facilities for the ATC program have been purchased with third party grant monies from the National Science Foundation and the Society of Manufacturing Engineers, most of the equipment is made available under various terms by industry partners.

The lab contains a significant amount of automation hardware that is linked together in fully integrated systems. This equipment is used to teach students pneumatics, electronics of sensing and solenoid technologies. All equipment is controlled by programmable logic controllers, which have very sophisticated human-machine interfaces. Students are required to work in these labs on a regular basis, so their training is hands-on and practical.

Because of its huge investment in automation and mechatronic equipment, ATC’s technology and labs are far more advanced than local four-year universities. ATC has offered to enter into partnerships with these colleges so that they can share resources and teach hand-on applications to university students and faculty. This kind of arrangement can also serve as a ground for a 2 + 2 articulation agreement and represents a great opportunity for Texas colleges to develop collaborations with local- and state-wide universities.

Faculty

There are four individuals on the faculty, one of whom was scheduled to retire at the end of 2006. The ATC faculty has many years of practical, industry experience in areas closely related to mechatronics, such as programmable logic controllers, automation, networking and advanced automation. Additionally, program faculty have enhanced their mechatronic credentials through internships with automation and control manufacturers and through their activities in corporate training courses. These activities help to assure that the program is up-to-date on industry changes.

As instructors, we put as much emphasis on teaching employees from industry in our customized training programs as we do on instructing our regular students. I can sit here and teach an 18-year-old, 10-year-old technology for two years and they will never know the level of my malpractice until they enter the workforce and realize that they don’t know anything. If I do that once to an industry customer, I have relegated myself to irrelevancy to that company. This exposure helps us keep our teachings relevant and timely.

Ken Ryan, Center for Automation and Motion Control, Alexandria Technical College
Suggestions for New Mechatronics Programs

Ken Ryan, Center for Automation and Motion Control, Alexandria Technical College

States wishing to initiate mechatronic programs should begin by establishing Centers of Excellence in mechatronics. Schools have to say “innovate don’t replicate.” Fund one, two or three institutions that are doing an outstanding job of developing curriculum. Then, let those colleges be the centers of curriculum distribution to other colleges. On a statewide level, there may be several different types of mechatronic programs based on local industry composition (e.g., one for the packaging industry, one may be for the semiconductor industry, one for the energy industry). These Centers should be funded until they can no longer meet the demand for their services. These emerging Centers of Excellence can be used to teach other colleges how to construct programs.

Note: This information is based on an interview with Mr. Ken Ryan, Instructor in the Center for Automation and Motion Control, Alexandria Technical College, Minnesota (Email: kenr@alx.tec.mn.us, Phone: 320-762-4461). The interview was conducted June 27, 2006.

Sierra College

The mechatronic program at Sierra College grew out of discussions between the college and representatives from local industry that were members of the college’s advisory committees. These discussions centered around the employment opportunities for graduates with a broad technical skill set that included not only electronics but also computer maintenance and troubleshooting, mechanical technologies, hydraulics, pneumatics, automation and production control. Through this research, it became obvious to Sierra that the proper name for a program that taught this broad of an array of skills was mechatronics.

Sierra then pursued a grant from the Chancellor’s Office of The California Community Colleges to review programs from across the country and gather a set of model curricula and best practices that the college could draw from in constructing its programs.

Program Description

In constructing the mechatronic program, Sierra College attempted to develop a program that could transfer a common set of skills that students who entered a variety of industries could use. Ultimately, Sierra developed a curriculum that included both significant modifications to existing classes, as well as the creation of three new classes to round out the curriculum.
### Exhibit 5.2. Sierra College Entry-Level Mechatronics Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIE 10</td>
<td>Basic Electronics Circuits and Devices</td>
<td>Testing, measurement and troubleshooting of electronics.</td>
</tr>
<tr>
<td>CIE 25</td>
<td>Computer Configuration, Repair and Troubleshooting</td>
<td>How computers are used as the central platform for most control systems.</td>
</tr>
<tr>
<td>CIE 4</td>
<td>Mechatronics Systems</td>
<td>Basics of electrical systems, safety, control of prime movers, electric motors, fluid power (hydraulics and pneumatics) and PLCs.</td>
</tr>
<tr>
<td>CIE 44</td>
<td>Mechatronics Materials and Processes</td>
<td>Fabrication course that covers the proper use of hand and machine tools in converting raw products into finished items. As a semester project, students build a desktop robotic arm completely from scratch. There are no prefabricated parts. At the end of the semester, students must be able to program the microcontroller that controls the motion of the robotic arm. The robot has stepper motors for rotational motion at the base, a pneumatic system for lifting the arms and solenoids for the grip. Upon completing the course, students are allowed to keep their robotic arm and are encouraged to use it for demonstration purposes to potential employers.</td>
</tr>
</tbody>
</table>

### Exhibit 5.3. Sierra College Capstone Mechatronics Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIE 14</td>
<td>Electronic Fabrication Course</td>
<td>Electronic assembly such as wiring, soldering and PCBs. Ultimately, students build a custom designed bench-top laboratory power supply. The ultimate goal of the course is to demonstrate for students how electronic assemblies are mechanically packaged.</td>
</tr>
<tr>
<td>CIE 54</td>
<td>Mechatronics Systems</td>
<td>Demonstrate how automated systems, composed of multiple control devices (PLCs), are linked together into networks to coordinate operations between more than one system. The course also addresses hydraulics and three phase power control (transformers, motors, variable frequency drives, etc.).</td>
</tr>
<tr>
<td>CIE 90</td>
<td>Microcontroller Embedded Systems</td>
<td>This course covers mechatronics and embedded systems. Each student who completes the CIE 90 course is responsible for building a term project of their own design that includes a microcontroller. At this point in the program, students will have enough background in the component pieces to take an idea and carry it through to a final project over the span of about half a semester. The course empowers students—they know that they have learned a sufficient amount of skills in a broad range of areas and can solve a real problem.</td>
</tr>
</tbody>
</table>
The mechatronic courses at Sierra are project-based and hands-on. Throughout their programs of study, students are required to complete projects that coalesce different topics into a finished device that best illustrates the mechatronic concepts that a specific course is designed to convey.

**Current Status**

The program development process started in 2003 and the program accepted its first students in fall 2005.

There are a total of 350 students in Sierra’s College of Technology, with about half of these students enrolled in the mechatronic program. The other students are enrolled in the traditional electronics technology program or the computer repair, maintenance and troubleshooting program. At the end of the year, Michael Halbern, director of the program, expects 15 to 20 students to graduate from the program.

**Employment Opportunities**

Many of Sierra’s business partners have told the college that they are not looking for specialists in one specific line of technology. In their entry-level employees, they are looking for people with a broad base in a variety of different skills. The companies will then provide on-the-job training to bring those entry-level employees up to speed and productivity in their specific job category.

Sierra College’s industry service base spans a wide variety of industries that have a need for technicians with mechatronics-related skills. This base includes companies all the way from Union Pacific Railroad to NEC that uses Class 1000 clean rooms for semiconductor manufacturing.

Salaries for mechatronic technicians start from $32,000 and $35,000 and typically grow to about $50,000 after three to five years. Students in the Sierra mechatronic program are often hired before they graduate.

**Laboratory Facilities**

Industry partners have contributed a considerable amount of laboratory equipment. For example the Native American Gaming Industry has contributed slot machines and Diebold has donated ATM machines.

**Faculty**

Sierra College has a faculty with broad experience not only in electronics, but also in mechanics and industrial controls and maintenance. This breadth of experience has helped the college to transition from electronics to the new area of mechatronics focused on mechanics and control systems.
Relationship with Industry

Stephanie Guevara, Dean, Business and Technology Division, Sierra College

For a program like Sierra’s mechatronic program to be successful, it must be industry driven. This program would not be sustainable without strong and very honest industry input into curriculum development and the skill level and skill sets that employers expect to see from students when they complete the program. In fact, Sierra's mechatronic program has attracted industry partners that the college never expected to have. Out of the woodwork, about half a dozen employers have come to Sierra after reading descriptions in the local media about the program. They recognized that the program was producing the kinds of entry-level technicians that they needed.

Suggestions for New Mechatronics Programs

Michael Halbern, Director, Sierra Mechatronics Program

To be successful, a program like mechatronics must have support from every level of the college and the community that it serves. Support for the program must span departments within a college (mechanics, electronics, control systems, etc). A mechatronic program is an expensive program to put together and an expensive program to maintain. The laboratory equipment that is required is very costly. Therefore, these programs require a commitment all up and down the educational food chain in order to be successful. Not all mechatronic programs need to be clones of each other. Each one should most appropriately fit the employment opportunities within its region.

Note: This information is based on an interview with Stephanie Guevara, Dean, Business and Technology Division, Sierra College, Michael Halbern, Director of Mechatronics Program, Sierra College and Luis Sanchez, Instructor, Mechatronics Program (email: sguevara@sierracollege.ed, Phone: 916-781-0585). The interview was conducted July 3, 2006.

Kentucky Community and Technical College System (KCTCS)

The state of Kentucky has contracted with Siemens to train instructors in the Kentucky Community and Technical College System (KCTCS) in mechatronics. The goal is to certify instructors capable of teaching the Siemens mechatronic certification and the coursework on which it is based, to students of the KCTCS. Once these instructors have been certified, KCTCS will be the prime and sole institution to offer the Siemens certification training in the United States. This does not preclude the certification of people who have not taken the courses from KCTCS; it just means that KCTCS is the only institution that can offer the training.

Program Description

Siemens has four subject areas in which instructors will have to be certified: mechanical systems, computer systems, electrical systems and control systems. Obviously, students seeking certification are also being trained in these subject areas.
The KCTCS is not establishing an AAS in mechatronics. Students who want to achieve the mechatronic certification will come from AAS programs such as electrical technology, industrial maintenance and instrumentation. KCTCS will conduct a substantial amount of mechatronic training, but within the architecture of these existing programs. In addition, there will be some number of Capstone courses that emphasize ideas that will be tested in the Siemens certification exam.

**Program Status**

KCTCS plans to implement mechatronic training at its two-year colleges in the next two to three years.

**Laboratory Facilities**

WKCTC is currently building a 50,000 square foot Emerging Technology Center on its campus that will have lab facilities for training in a number of technical disciplines, including mechatronics (robotics).

**Faculty**

The backgrounds of the KCTCS faculty who are completing the Siemens training include electrical technology, instrumentation, electromechanical systems, computers, information technology and robotics.

For the Siemens program, KCTCS will have to certify the instructors who will be conducting the mechatronic training. To achieve that certification, instructors have to complete two weeks of training at the Siemens Technical Academy in Berlin. The training is called Mechatronics Systems Approach Learning Strategies and is used by Siemens to certify its employees that service and maintain the company’s manufactured goods and systems. These systems range from electrical and electronics components to x-ray equipment and mass transportation systems.

The training for instructor certification is composed of three tiers (Level I, Level II and Level III) with 14 individual courses.

The training that KCTCS faculty received in Berlin was the first two courses in Level I. The next two courses in Level I are taught by German instructors in the United States. At the conclusion of the one-week training period, the KCTCS faculty receives certification once they pass an exam. This certification permits them to teach Level I Mechatronics for plant operators. The requirements for the Level II and Level III certification are still being developed.

- Level I certification is for an employee who wants to be a line operator in a manufacturing plant. This person can perform basic troubleshooting tasks and get machines back online without a lot of delay.
- Level II is a system technician who will actually be a chief troubleshooter.
- Level III is a system engineer.
It is expected that Level I and Level II technicians will come from two-year colleges. Level III technicians will come from the four-year engineering universities.

**Employment Opportunities**

It is estimated that entry-level mechatronic technicians will start at about $35,000 in the Kentucky area. In the future, it is expected that AAS graduates will be ready to become Level II technicians, which should result in higher starting salaries.

**Relations with Industry**

The state of Kentucky believes that these training programs will attract manufacturing companies to the state because they can have confidence that a well-trained workforce is available.

**Student Recruitment**

KCTCS is working with local high schools to initiate pre-engineering curricula. KCTCS is linking with these high schools through dual credit or dual enrollment programs that allow students to earn college level mechatronics-related credit while they are still in high school.

**Recommendations for New Mechatronic Programs**

*Dr. Ronald McMurtry, Director of K-12 Partnerships and Professor of Electrical Technology, Western Kentucky Community and Technical Colleges*

The term mechatronics has many different meanings to many different people, and there are many different “mechatronics” curricula. However, when you talk about mechatronic faculty certification with a world-renowned engineering/manufacturing company like Siemens, it gives the term a clearly defined meaning. This validation has meaning to employers.

*Note:* This information is based on an interview with Dr. Ronald McMurtry, Director of K-12 Partnerships and Professor of Electrical Technology, Western Kentucky Community and Technical Colleges (email: ron.mcmurtry@kctcs.edu, Phone: (270)534-3391). The interview was conducted June 23, 2006.

**Government and Trade Association Sources**

There are a number of funding sources that support curriculum development in the area of advanced manufacturing. Relevant programs include the following:
National Science Foundation Advanced Technological Education Program

The National Science Foundation (NSF) Advanced Technological Education (ATE) program supports projects that develop technicians for advanced technology industries. The program utilizes educators from two-year colleges to develop and implement ideas and curriculum for improving the skills of technicians and the educators who teach them. ATE centers support collaboration among educational institutions and industry partners through formal cooperative agreements. By mandate, ATE centers must provide nationally usable model curricula for other institutions.

Existing ATE centers directly relevant to mechatronics include the National Center for Manufacturing Education, the California Regional Consortium for Engineering Advances in Technological Education (CREATE), the Florida Advanced Technological Education Center, the New Jersey Center for Advanced Technological Education (NJCATE), the Regional Center for Next Generation Manufacturing, the South Carolina Advanced Technological Education Center of Excellence and the National Center for Optics and Photonics Education (Op-Tec) headquartered at CORD in Waco, Texas. Visit www.atecenters.org for more information.

Society of Manufacturing Engineers Manufacturing Education Plan

The Society of Manufacturing Engineers Manufacturing Education Plan (MEP) supports the efforts of education institutions to develop and improve manufacturing engineering and technology education programs. Through academia-industry cooperation, SME's goal is to increase manufacturing productivity. MEP is specifically interested in supporting projects that:

- Provide practical experience to students through internships and apprenticeship programs.
- Encourage academic/industry collaboration.
- Provide for the transfer of technical knowledge and curricula development materials to other educational institutions.
- Provide specifications for the transfer of technical knowledge and/or teaching methodologies to other educational institutions.
- Integrate two or more of the following areas: capital equipment for curriculum development, curriculum development, faculty development, student outreach and development (to support curriculum development) and multidisciplinary programs that not only connect an educational institution’s technical programs but also its nontechnical programs.

Alexandria Technical College received a $200,000 MEP grant to establish the Minnesota Center for Advanced Manufacturing Automation, which is developing...
curriculum materials and high school outreach programs in the area of mechatronics. According to Ken Ryan, a grant reviewer for the SME MEP program, a substantial amount of money from that grant source goes unused each year because it requires that applying institutions provide one-to-one matching funds. Visit www.sme.org for more information.

**President George W. Bush’s High Growth Job Training Initiative for Advanced Manufacturing**

The President’s High Growth Job Training Initiative is “designed to provide national leadership for a demand-driven workforce system.” This program identifies critical workforce challenges and then invests in training programs that address identified gaps. Advanced manufacturing is one of the targeted industry sectors included in this program and is specifically designed to address many of the technological and workforce challenges related to manufacturing and addressed in this report. Grants are awarded to regional entities in cooperation with employers, educational institutions and the public workforce system.

Based on interviews with industry experts and research into the challenges facing U.S. manufacturing, the ETA gathered solutions into three categories:

- **Capacity Building**: Ensuring that the infrastructure of training and education programs exists to train an adequate supply of workers for advanced manufacturing.

- **Pipeline Development**: Maintains practices and processes to ensure that an ongoing supply of new and incumbent workers are recruited and prepared to meet the needs of manufacturers.

- **Training for Innovation**: Ensuring that training and education programs are aligned with the needs of employers and that trainees can provide innovative and creative solutions for employers.

Visit www.doleta.gov/BRG/Indprof/Manufacturing.cfm for more information.

**Manufacturing Skill Standards Council (MSSC)**

The Manufacturing Skill Standards Council (MSSC) has initiated a foundational certification program to assess and measure technicians industry validated KSAs for all manufacturing sectors. Passage of the certification exam qualifies a technician as a “Manufacturing Production Technician” competent in four areas: manufacturing processes and production; quality assurance; maintenance awareness; and health, safety and environmental assurance. The certification is a basic standard and much less rigorous than the programs described above. Visit www.msscusa.org for more information.
Chapter Six: Conclusions

Increasing the number of college trained mechatronics technicians is of importance to many Texas industries. First of all, as increasing numbers of experienced technicians of the “baby boomer” generation reach retirement age, Texas companies, like their counterparts in other states, must find technicians capable of replacing multi-craft mechatronics technicians who have acquired their knowledge and skills while on the job. 2,058 job openings will be created in mechatronics-related occupations in Texas each year through 2012. Of these, 64% (1,331) will come from the replacement of existing workers.

1) Retirement of baby boomers from technical trades affiliated with mechatronics has implications beyond the aggregate numbers. Specifically, Texas and many of the US states face a discontinuity in the transfer of knowledge between older and younger generations of workers. This discontinuity in knowledge transfer has profound and possible deleterious implications for Texas economic competitiveness and labor productivity.

2) Texas should make investments in mentoring and training programs that work to transfer knowledge among older and younger generations related to multi-craft skills and legacy systems. Of particular importance will be the maintenance and operation of legacy systems in addition to newer more integrated mechatronic systems.

3) Mechatronics training should target the entire educational and workforce system including primary education, secondary education, post secondary education and training for incumbent and dislocated workers. Starting early is important because the general systems nature of mechatronics provides a foundation to connect previously separate areas of academic study into a unified whole with the possibility of creating young learners able to think and act systemically. Mechatronics systems are likely to become increasingly important over time as skilled labor continues to displace unskilled labor in all facets of the US economy.

Mechatronics programs can produce students who are prepared to enter industry as multi-craft technicians. Colleges with existing electronics technology, electrical systems, mechanical engineering technology, electromechanical engineering technology, industrial engineering, robotics and computerized control systems programs are well positioned to create such programs.

4) Colleges with these facilities, relevant human capital and industry support should work to integrate and restructure the teaching of science, technology, engineering and mathematics. A qualitative transformation in the production of innovators should also be considered by integrating the Arts (specifically design) and Career and Technical Education (CTSE) into a systemic STEM strategy.

5) Similarly, colleges should reach down to K-12 and support K-12 teacher training and the development of curricula for K-12 programs to develop general systems knowledge and a systemic and applied architecture for teaching STEM.
Specifically, a general systems approach to curricula should emphasize: (1) teaching of mathematics, physics, computer science, engineering and (2) teaching of biology and chemistry in concert with the aforementioned subjects to form an integrated system of knowledge and learning.

6) Texas should focus at least have one K-12 educational initiative in an area of real potential to create human capital with innovation capacity in the face of rapidly expanding scientific and technical knowledge. Models exist for this holistic educational integration including the US FIRST middle school challenge “Nano Quest.” During the 2006-2007 academic year, 80,000 middle school students will participate in a robotics competition that delivers, at least, a stake in the ground that unifies the teaching and leaning of physics, chemistry, biology, mathematics, computer science, engineering and design (Art). See Appendix E for more details.

7) Texas colleges and universities and the Texas Higher Education Coordinating Board should also develop or assist in the development of relevant transfer and articulation agreements with high schools and universities. Specifically, THECB should develop a state-wide articulation agreement that guarantees mechatronics college and university credits will be accepted by all Texas post secondary schools with appropriate rigor and relevant programs.

A challenge for colleges will be integrating the distinct disciplines that form mechatronics into a cohesive program that teaches multi-craft technicians. A number of colleges in the United States have created such programs and graduates of those programs have found high-paying jobs with excellent career opportunities.

8) Colleges considering the initiation of a mechatronics program must have the support of a broad range of stakeholders including administrators, faculty, employers, potential students and their parents who may be skeptical of employment opportunities in technical fields.

9) Colleges should organize outreach efforts including industry tours, lectures and marketing initiatives to educate K-12 leaders, parents and students about opportunities in multi-craft technical industries including: Biotechnology, Life Science & Medical; Electronics & Applied Computer Equipment; Telecommunications & Information Services; Distribution, Transportation & Logistics; Heavy & Special Trade Construction; Energy, Mining & Related Support Services; Petroleum Refining & Chemical; Transportation Equipment; Production Support & Industrial Machinery; Agriculture, Forestry & Food; Aerospace, Homeland Security and Defense.

Since the term mechatronics was first coined by Tetsuro Mori in 1969, it has described the multidisciplinary application of mechanics, electronics, control systems and computer systems to improve the functionality of industrial products and processes. Today, mechatronics is pervasive in modern industry across all of Governor Rick Perry’s targeted industry clusters and it is the foundation manufacturing technology of micro-, meso- and nano-scale systems.
10) We should anticipate that mechatronic technologies may advance along a similar trajectory as the growth of the Internet and that workers will need to be capable of both physical and mental labor characterized by integration of previously distinct academic disciplines, skills and occupations.

Mechatronics is a catalyst for integration of academic disciplines (knowledge mergers), the integration of applied skills within occupational practice (skill mergers) and the integration of distinct occupations (job mergers). This trend toward multi-craft represents an opportunity, however, if we fail to act, Texas risks missing a great economic and technological wave which is transforming the nature of work from unskilled to skilled labor and technology education from what was once considered trade and vocational to highly advanced career and technical education. By embracing mechatronics and its advancements to micro-to-nano scale technologies, Texas can has an opportunity to lead the world in anticipating and acting on the knowledge that 21st century innovation is characterized by systemically organizing education and work around common integrative (or general systems) principles. Namely, principles of innovation: Multidisciplinarity, Multi-Craft and Multi-Industry Collaboration.
Appendix A: Survey

A major source of information for this project was a survey conducted by Technology Futures, in conjunction with the Texas State Technical College System. The 41 survey participants represented a wide range of Texas companies that employ mechatronics-related technicians. This appendix contains a copy of the survey and a list of survey participants.

Survey Questions

**Mechatronics: Survey of Trends, Technologies, and Workforce Needs**

The purpose of this survey is to assess and highlight important industry, market and technology trends as well as determining the workforce and curricula needs of industry in the state of Texas. The results of the survey will be reviewed by key decision makers in the state’s community and technical college and economic development organizations. Your participation will help ensure that your organization has the skilled workforce required to effectively compete in the global 21st century.

I. Information about Your Organization

1) Contact and Company Information

<table>
<thead>
<tr>
<th>First Name</th>
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<tbody>
<tr>
<td>Last Name</td>
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<tr>
<td>Title</td>
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<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>City</td>
<td></td>
</tr>
<tr>
<td>Zip Code</td>
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</tr>
</tbody>
</table>
2) What is the primary business of your company?
   - Manufacturer of electronic products (e.g., semiconductors, MEMS, computers, servers, printers, etc.)
   - Manufacturer of consumer products (e.g., household items, clothing, toys, etc.)
   - Manufacturer of large commercial items (e.g., airplanes, automotive vehicles, industrial equipment, etc)
   - Agricultural and Food Processing
   - Oil and Gas Production
   - Petroleum Refining and Chemical Products
   - Power Generation, Transmission, and Distribution
   - Service provision (e.g., consulting, manufacturing support services, etc.)
   - Other (please specify)

   If you selected other, please specify:

3) How many employees does your organization currently employ?
   - None
   - 1–100
   - 101–500
   - 501–1000
   - 1001–10000
   - More than 10000

4) Of these employees, how many are technicians in the fields of mechanics and/or electronic or electromechanical systems. Examples would include technicians who are responsible for the installation, repair, and calibration of equipment in the field of robotics, electronic instrumentation, machine vision, hydraulics, pneumatics, feedback control systems, software and networked systems?
   - None
   - 1–5
   - 6–20
   - 21–50
   - 51–100
   - 101–500
   - More than 500
II. Mechatronics Technicians

A qualified Mechatronics Technician must have at least a general knowledge of all or most of these technologies listed in Question 4 and, in addition, have an ability to understand how multiple technologies can be utilized holistically (i.e. in concert) in manufacturing and service provision operations.

5) Of the technicians listed in Question 4, what percentage is qualified to be regarded as Mechatronics Technicians?
   o None
   o 10%
   o 25%
   o 50%
   o All

6) Of the technicians listed in Question 4, what percentage could be qualified to be regarded as Mechatronics Technician with two-years’ Mechatronics training at a community or technical college (CTC) or equivalent training?
   o None
   o 10%
   o 25%
   o 50%
   o All

7) Assuming that your organization could find individuals with the skills and knowledge required for competent Mechatronics Technicians, how many new Mechatronics Technicians would you anticipate hiring in the next twelve months?
   o None
   o 1–3
   o 4–6
   o 7–15
   o 16–25
   o 26–50
   o More than 50
8) Assuming that your organization could find individuals with the skills and knowledge required for competent Mechatronics Technicians, how many new Mechatronics Technicians would you anticipate hiring in the next one to three years?
   • None
   • 1–3
   • 4–6
   • 7–15
   • 16–25
   • 26–50
   • More than 50

9) What is the average starting salary of entry-level technicians who perform mechatronic functions in your organization?
   • $20,000–$25,000 ($9.60–$12.00/hr)
   • $25,000–$30,000 ($12.00–$14.40/hr)
   • $30,000–$35,000 ($14.40–$16.80/hr)
   • $35,000–$45,000 ($16.80–$21.65/hr)
   • $45,000–$55,000 ($21.65–$26.45/hr)
   • More than $55,000 (More than $26.45/hr)

10) What is the average salary of technicians who perform mechatronics functions in your organization after five years of experience?
    • $20,000–$25,000 ($9.60–$12.00/hr)
    • $25,000–$30,000 ($12.00–$14.40/hr)
    • $30,000–$35,000 ($14.40–$16.80/hr)
    • $35,000–$45,000 ($16.80–$21.65/hr)
    • $45,000–$55,000 ($21.65–$26.45/hr)
    • More than $55,000 (More than $26.45/hr)
11) What would these technicians’ primary duties involve?

<table>
<thead>
<tr>
<th>Primary</th>
<th>Secondary</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Installation</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Calibration</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Maintenance</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Retrofitting</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Repair</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Additional comments:

12) What has been the best source of fully qualified technicians who perform mechatronics tasks, for your organization during the past 3 years?

- Community and Technical Colleges
- Proprietary Trade Schools and Technical Institutes
- Apprenticeship Programs
- On-Line Training Programs
- In-House Training
- Hiring Away from Competitors
- Other (please specify)

If you selected other, please specify:

13) On a Scale of 10 (highest) to 1 (lowest), how would you rate the employment attractiveness of potential employees with the following qualifications:

A community or technical college (CTC) graduate with a two-year Associate Degree in a field of study directly related to Mechatronics such as robotics or electromechanical systems, but with no field experience

A community or technical college (CTC) graduate with a one-year Certificate in Mechatronics, but with no field experience

A community or technical college (CTC) graduate with a one-year Certificate in an area directly related to Mechatronics such as robotics or electromechanical systems, but with no field experience.
A person with three-years in a related field such as mechanics, robotics, electronics, or controls, but no specific Mechatronics training

A person with three-years in a related field such as mechanics, robotics, electronics, or controls with a one-year CTC Mechatronics certificate

A person with three-years in a related field such as mechanics, electronics, robotics, or controls with a two-year CTC Associate Degree in Mechatronics

14) On a Scale of 10 (highest) to 1 (lowest) how would you rate the importance of the following capabilities for Mechatronics Technicians?

Effectively employ computer guided monitoring, diagnostic, and trouble-shooting systems to evaluate complex, (mechatronic) systems

Monitor and maintain multivariate statistical process control (SPC) systems

Work, build, maintain, and trouble-shoot electronic and logic systems from schematics

Participate in and contribute to continuous improvement activities

Exhibit highly creative and/or abstract thinking

Understand and appreciate complex systems

Analyze the effects of complex tool system interactions and variations

Trouble-shoot down to the macro or module level

Communicate effectively orally including formal and informal presentations

Communicate effectively in writing including preparation of reports

Work efficiently and effectively when working individually

Work efficiently, effectively, and collaboratively as a member of a team

Have a strong work ethic

Other (please specify)
15) To what degree do you agree or disagree with the following statements?

<table>
<thead>
<tr>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Have no position</th>
<th>Disagree</th>
<th>Strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>A properly designed and conducted two-year CTC mechatronics program can provide graduates with the skills required for successful employment as a Mechatronics Technician</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>On-the-job experience in a related skill area is the most effective path for gaining the skills required for successful employment as a Mechatronics Technician</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Most technicians hired in recent years have had to become Mechatronic Technicians, typically through on-the-job training, in order to maintain job competency</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Formal mechatronics training can materially decrease the time necessary to gain the skills required for successful mechatronics employment</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Mechatronics offers particularly attractive employment opportunities for people seeking new career paths</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The requirement for multiple skills will limit the number of people who can become effective Mechatronics Technicians</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>The ability to integrate a variety of skills will be increasingly important for technicians to maintain attractive positions in industry</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>In general terms, increases in the employment of Mechatronics Technicians will be balanced by decreases in employment in related traditionally defined fields, such as electronics, computer, and mechanics technicians</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Additional comments:

16) Please list any further thoughts that you have about the training, certification, or utilization of Mechatronics Technicians.


17) I am available for telephone or in-person interviews?

O Yes   O No
Texas State Technical College and Technology Futures, Inc. thank you for your participation.

### Survey Participants

<table>
<thead>
<tr>
<th>Organization</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARM Automation</td>
<td>Austin</td>
</tr>
<tr>
<td>Tokyo Electron</td>
<td>Austin</td>
</tr>
<tr>
<td>OsteoMed</td>
<td>Austin</td>
</tr>
<tr>
<td>Reed Hycalog</td>
<td>Houston</td>
</tr>
<tr>
<td>Hydraquip Corporation</td>
<td>Houston</td>
</tr>
<tr>
<td>Wilson Company</td>
<td>San Antonio</td>
</tr>
<tr>
<td>Entech Sales and Service</td>
<td>Austin</td>
</tr>
<tr>
<td>Packless Industries*</td>
<td>Waco</td>
</tr>
<tr>
<td>Saint Gobain Corporation</td>
<td>Stephenville</td>
</tr>
<tr>
<td>Yokogawa Corporation of America</td>
<td>Sugar Land</td>
</tr>
<tr>
<td>Sherwin Alumina</td>
<td>Corpus Christi</td>
</tr>
<tr>
<td>Gulf Aviation</td>
<td>Harlingen</td>
</tr>
<tr>
<td>AEP Industries</td>
<td>Waxahachie</td>
</tr>
<tr>
<td>ITA</td>
<td>Fort Worth</td>
</tr>
<tr>
<td>Samsung Austin Semiconductor*</td>
<td>Austin</td>
</tr>
<tr>
<td>Lockheed Martin–Harlingen Operations*</td>
<td>Harlingen</td>
</tr>
<tr>
<td>Alcoa</td>
<td>Rockdale</td>
</tr>
<tr>
<td>EADS</td>
<td>Dallas</td>
</tr>
<tr>
<td>Advanced Micro Devices</td>
<td>Austin</td>
</tr>
<tr>
<td>ConocoPhillips</td>
<td>Sweeny</td>
</tr>
<tr>
<td>Spectra Physics</td>
<td>Hewitt (Waco)</td>
</tr>
<tr>
<td>Owens Corning</td>
<td>Waxahachie (DFW)</td>
</tr>
<tr>
<td>Lower Colorado River Authority</td>
<td>Austin</td>
</tr>
<tr>
<td>PBV-USA</td>
<td>Houston</td>
</tr>
<tr>
<td>TXU Power*</td>
<td>Dallas</td>
</tr>
<tr>
<td>Johnson Controls</td>
<td>Irving</td>
</tr>
<tr>
<td>Holcim</td>
<td>Midlothian (DFW)</td>
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<tr>
<td>Eastman</td>
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<tr>
<td>Spansion</td>
<td>Austin</td>
</tr>
<tr>
<td>Temple Inland</td>
<td>Diboll (Lufkin)</td>
</tr>
<tr>
<td>Formosa Plastics</td>
<td>Point Comfort (Victoria)</td>
</tr>
<tr>
<td>Bayer Material Science</td>
<td>Baytown</td>
</tr>
<tr>
<td>Dow Chemical Company</td>
<td>Baytown</td>
</tr>
<tr>
<td>ADIT</td>
<td>Sweetwater</td>
</tr>
<tr>
<td>The Laser Medic</td>
<td>Bedford (DFW)</td>
</tr>
<tr>
<td>Hydraulic Works</td>
<td>Bryan</td>
</tr>
</tbody>
</table>

* Indicates that more than one respondent from the company answered the survey
Appendix B: Experts Consulted

A series of personal and telephone interviews were conducted by the authors during the course of this project. The information, opinions, and insights gathered during these interviews had the characteristics of being authoritative, timely, and relevant. The authors conducted a total of 16 formal interviews and a number of informal interviews. The people with whom formal interviews were conducted, together with a brief synopsis of the subjects covered during the interviews, are listed below.

**Derek Black**—**Vice President, ARM Automation.** ARM builds, designs, and integrates automation systems. Derek supplied valuable insights about the use of automation and robotics equipment in Texas industry. Derek also provided information about the KSAs required of technicians who install and maintain that equipment.

**Christine Costi**—**Sales and Marketing Manager, ACS Controls.** ACS is a systems integrator of HVAC building automation controls systems, security access, and CCTV monitoring installations. It played a significant role in the establishment of the mechatronics program at Sierra College, and currently is on the program’s advisory committee. Costi provided valuable information about establishing the program and the demand for mechatronic technicians in the building automation industry.

**Jim Coyle**—**Service Manager, Roger Beasley Volvo.** Jim supplied insights about the training and apprenticeship of automobile technicians within the Volvo service and repair environment.

**Nick Denardo**—**Instructional Design and Development Supervisor, Tokyo Electron.** Tokyo Electron is the world’s second largest manufacturer of semiconductor production equipment. Nick is responsible for constructing the training programs that prepare technicians to maintain, calibrate, and service this equipment after it is sold to customers. Nick supplied valuable insights about the training of interdisciplinary field technicians in the semiconductor equipment industry.

**Stephanie Guevara**—**Dean, Business and Technology Division, Sierra College.** Stephanie provided valuable insights about the creation of the mechatronics program at Sierra college, and the demand for mechatronics technicians.

**Michael Halbern**—**Instructor and Director of the Sierra College Mechatronics Program.** Michael supplied insights about the structure and content of courses within the Sierra mechatronics program. He also provided valuable information concerning the KSAs and employment prospects of graduates of the program.

**Pat Hobbs**—**Vice President of Student Learning, Texas State Technical College Harlingen.** Pat supplied insights about the establishment of the mechatronics program at Harlingen and the need for interdisciplinary technicians in the Valley region.
David James—Senior Manager, Utility Operations & Maintenance, Samsung. David supplied insights about the need (i.e., shortage) for skilled technicians in certain critical manufacturing positions in Texas.

Fred Khozein—Vice President of Student Learning, Texas State Technical College Waco. Fred supplied insights about employment opportunities for graduates in mechatronics programs at Texas State Technical College Waco. He also provided information concerning enrollment and graduate rates for those programs.

Albert Margolis—President, Hobby Engineering, childhood interests in electronics and robotics started in 1964 at age 11. Thanks for the 43 years of wisdom and the help with Appendix E.

Dr. Ronald McMurtry—Director of K-12 Partnerships and Professor of Electrical Technology, West Kentucky Community College. Ron supplied information about the Siemens mechatronics faculty certification training program and the efforts the college to incorporate that training into existing Associate degree programs.

Dr. Mary Pat Moyer—Dr. Mary Pat Moyer is a recognized biomedical scientist, entrepreneur and technology business leader. She founded the innovative life sciences company, INCELL Corporation (1993; www.incell.com ), after over 20 years as an academic scientist, most recently as Director of the Center for Human Cell Biotechnology, Division Head of Surgical Research, and Professor of Surgery, Microbiology, Cellular and Structural Biology, Pediatrics, and Molecular Medicine at the University of Texas Health Science Center at San Antonio.

Sam Nauman—Director of Advanced Manufacturing Integrated Systems Technology Laboratory, Texas State Technical College Harlingen. Sam supplied information about the Advanced Manufacturing/Integrated Systems Technology Laboratory that has been established at Texas State Technical College Harlingen. He also provided valuable insights about the new mechatronics program at the college, and the demand for interdisciplinary technicians in the Valley region.

Dr. Mitchell Pryor—Associate Director of the University of Texas at Austin Robotics Research Group. Mitchell provided information about the research activities of the Robotics Research group within the Department of Mechanical Engineering at the University of Texas at Austin.

Dr. Ken Ryan—Instructor and Director, Center for Automation and Motion Control, Alexandria Technical College. Ken supplied valuable information about the teaching and industry related activities of the center, which is widely acknowledged as a leader in the development of mechatronics training at the two-year level. He also provided valuable information about government and industry funded programs that could be leveraged to establish new mechatronics programs.

Julian Serda—Senior Instructional Developer, Spansion Semiconductor (formerly AMD). Julian provided information about the demand for and training of interdisciplinary technicians in the semiconductor manufacturing environment at Spansion.
Dr. Delbert Tesar—Director of the University of Texas at Austin Robotics Research Group. Delbert provided information about the research activities of the Robotics Research Group. He also provided background information and insights concerning technical developments in robotics and mechatronics, especially in the area of low-weight actuators.

Will Thompson—Vice President of Student Learning, Texas State Technical College West Texas. Will provided valuable information about the demand for graduates of mechatronics related programs at Texas State Technical College West Texas.
Appendix C: Recommendation of Texas State Leadership Consortium for Curriculum Development

Develop a Core Curriculum in Mechatronics

A core curriculum will include common skills for mechatronics related technicians across a wide range of industry sectors. The curriculum will largely include existing courses that have been modified or, if appropriate, new courses developed to teach necessary skills. Since the industries represented within the Governor’s advanced manufacturing cluster represent a significant majority of the employment opportunities within mechatronics, a core curriculum should be closely aligned with economic development efforts and existing curriculum development plans related to the Governor’s Cluster Initiative.

Mechatronics is an advanced technical subject area and constitutes a convergence of established disciplines. While the authors of this report are not curriculum development experts, based on their research of existing mechatronics programs within the United States and as demonstrated within this report, a core mechatronics curriculum will require significant effort by instructional designers and faculty to successful integrate these traditionally disparate disciplines into one holistic degree program. Moreover, given the limited time allotted for an associate’s degree, it is recommended that transdisciplinary instructional design principles be utilized and that colleges avoid simply reorganizing existing courses in the more traditional multidisciplinary method.

Existing mechatronics programs provide a useful roadmap for program design and appear to fall into two categories: generalized and target industry-oriented. The Sierra College and Alexandria Technical College programs exemplify these approaches respectively and are discussed earlier in this report. Both of these approaches appear to be valid; however, the Sierra College approach is favored by the authors as it is better suited toward a generalized core curriculum.

As a side note, Dick Whipple, Director of Curriculum and Instruction at Southwest Texas Junior College and a member of the CCD, was in charge of the CCD’s efforts to establish an advanced manufacturing core curriculum. After reviewing the results of the authors’ presentation to the CCD, he has decided, instead, to establish a core curriculum in mechatronics. He feels that the subject matter included in a mechatronics curriculum encompasses the core elements of technical knowledge in the industries included in the advanced manufacturing cluster.
Appendix D: Mechatronics Company Directory

The following is a representative list of companies in each of the Governor’s Industry clusters. The authors believe the listed companies employ mechatronics principles in the delivery of goods and services. An asterisk has been placed next to the names of those companies that were either (1) interviewed for this project, (2) responded to the survey, or (3) have publicly expressed an interest in hiring mechatronics-related technicians from colleges. Information on all companies comes from their own Web sites.

Advanced Technologies and Manufacturing

This category includes four sub-clusters: nanotechnology and materials, micro-electromechanical systems, semiconductor manufacturing, and automotive manufacturing.

Semiconductor Manufacturing

Company Name: Advanced Micro Devices*
Location: Austin
Contact: Benjamin Jomok
Contact Email Address: benjamin.jomok@amd.com
Company URL: www.amd.com/us-en
Description: Advanced Micro Devices (AMD) is an manufacturer of integrated circuits based in Sunnyvale, California. It is the second-largest supplier of x86-compatible processors, and a leading supplier of non-volatile flash memory.

Company Name: Applied Materials
Location: Austin and Allen (DFW)
Contact: Randy Smith
Contact Email Address: Randy_Smith@amat.com
Company URL: www.appliedmaterials.com
Description: Applied Materials, Inc. is the world’s largest supplier of products and services to the semiconductor industry.

Company Name: Freescale (formerly Motorola)
Location: Austin
Contact: Kevin Stuckly
Contact Email Address: ra2511@email.sps.mot.com
Company URL: www.freescale.com
Description: Freescale Semiconductor, Inc. is a global leader in the design and manufacture of embedded semiconductors for wireless, networking, automotive, consumer and industrial markets.

Company Name: Samsung Austin Semiconductor*
Location: Austin
Contact: David James
Contact Email Address: djames@sas.samsung.com
Company URL: www.sas.samsung.com
Description: Samsung Austin is one of the most advanced semiconductor fabrication plants in the world. Samsung Austin produces dynamic random access memory (DRAM) chips, most commonly used in personal computers, workstations, and servers.

Company Name: Spansion (formerly AMD)
Location: Austin
Contact: Julian Serda
Contact Email Address: julianserda@yahoo.com
Company URL: www.spansion.com
Description: Spansion is a joint-venture between AMD and Fujitsu. Spansion is the largest company exclusively focused on developing, manufacturing, and marketing Flash memory.

Company Name: Texas Instruments
Location: Dallas
Contact: Ezra Pennermann
Contact Phone: (214) 480-2825
Company URL: www.ti.com
Description: Designer and manufacturer of digital signal processing solutions and semiconductor products.

Company Name: Tokyo Electron America
Location: Austin
Contact: Nick DeNardo
Contact Email Address: nicholas.denardo@us.tel.com
Company URL: www.tel.com
Description: Tokyo Electron America (TEA) is the North American sales and marketing arm of Tokyo Electron, the world’s second largest supplier of semiconductor production equipment. TEA sells and services the equipment made by its parent company, which also includes machines for probing microelectromechanical systems wafers and flat panel display fabrication equipment.

Automobile Manufacturing

Company Name: Toyota Manufacturing Company
Location: San Antonio
Contact: John Runge
Contact Email Address: john_runge@tmmna.com
Company URL: www.toyota.com/about/operations/manufacturing/texas
Description: Toyota Manufacturing has built a plant in San Antonio and will begin manufacturing the Toyota Tundra in late 2006.

Company Name: Toyota Manufacturing Supplier Network
Location: San Antonio – New Braunfels – Austin – Georgetown Corridor
Contact: Alamo WorkSource
Company URL: alamoworksource.org/toyota/suppliers.asp
Description: Toyota on-site suppliers of products and services.

Company Name: Takumi Stamping Texas
Location: San Antonio – Toyota (on-site supplier)
Contact: Human Resources
Contact Email Address: hr@takumitx.com
Company URL: www.takumitx.com/
Description: Toyota on-site supplier of various stamped metal parts.
Company Name: Futaba Industrial Texas Corp  
Location: San Antonio – Toyota (on-site supplier)  
Contact: Human Resources  
Contact Phone: (210) 927-2288  
Company URL: www.macraesbluebook.com/search/company.cfm?company=84625  
Description: Toyota on-site manufacturer and supplier of various plastic automotive parts.

Company Name: Toyoda Gosei Texas  
Location: San Antonio - Toyota (on-site supplier)  
Contact: Human Resources  
Contact Phone: (210) 927-2302  
Company URL: www.toyoda-gosei.com/Information/location/usa/index.html  
Description: Toyota on-site manufacturer and supplier of interior and exterior parts for automobiles.

**Micro-Electromechanical Systems**

Company Name: Texas Instruments  
Location: Dallas  
Contact: Larry Hornbeck  
Contact Email Address: l-hornbeck@ti.com  
Company URL: www.ti.com  
Description: Designer and manufacturer of micro-mirrors (digital light processors), accelerometers, optical switches, and RF switches.

Company Name: Colibrys (formerly Applied MEMS)*  
Location: Houston  
Contact: Kevin Speller  
Contact Email Address: kspeller@appliedmems.com  
Company URL: www.appliedmems.com  
Description: Designer and manufacturer of micro-g accelerometers for seismic oil and gas field exploration,

Company Name: TeraVicta*  
Location: Austin  
Contact: Brad Nelson  
Contact Email Address: bnelson@teravicta.com  
Company URL: www.teravicta.com  
Description: Designer and manufacturer of RF switches for electronics products such as cell phones.

Company Name: Raytheon-Dallas, RF MEMS Group  
Location: Dallas  
Contact: Brandon Pillans  
Contact Email Address: pillans@ieee.org  
Company URL: www.raytheon.com  
Description: Manufacturer of RF switches for communications applications.

**Nanotechnology**

Company Name: Zyvex  
Location: Richardson (DFW)  
Contact: Larry Hornbeck  
Contact Email Address: l-hornbeck@ti.com
Company Name: NovaCentrix*
Location: Austin
Contact: Steve Leach
Contact Email Address: Steve.Leach@novacentrix.com
Company URL: www.novacentrix.com/
Description: NovaCentrix is a manufacturer of nanometals for applications such as nanoscale conductive inks, anti-microbial coatings, and energetic materials.

Company Name: Applied Nanotechnologies*
Location: Austin
Contact: Dr. Zvi Yaniv
Contact Email Address: zyaniv@appliednanotech.net
Company URL: www.applied-nanotech.com/
Description: Applied Nanotechnologies fabricates carbon nanotubes and produces carbon nanotube based devices such as x-ray tubes, microwave amplifiers, gas discharge tubes and field emission cathodes etc.

Company Name: C Sixty
Location: Houston
Contact: Dr. Russ Lebovitz
Contact Phone: 713-748-3447
Company URL: www.csixty.com/
Description: C Sixty is a nanomedicine company that is developing biopharmaceutical applications of carbon fullerenes.

Aerospace and Defense

Company Name: Boeing (Johnson Space Center)
Location: Houston
Contact: Kevin Howard
Contact Email Address: Kevin.m.howard@boeing.com
Company URL: www.boeing.com
Description: Boeing is the prime contractor responsible for the design, development, construction and integration of the International Space Station.

Company Name: L3 Communications Integrated Systems
Location: Waco
Contact: David Charro
Contact Phone Number: (254) 799-5533
Company URL: www.l-3com.com/is/waco/index.html
Description: L-3 Communications Integrated Systems Waco is a full-service aircraft modification center that features 430,000 square feet of hangar space, and the ability to accommodate aircraft of all sizes, from small rotor-wing aircraft to widebody jets.

Company Name: Dallas Airmotive
Location: Dallas
Contact: Keith Shaw
Contact Email Address: kshaw@dallasairmotive.com
Company URL: www.dallasairmotive.com
Description: Founded in 1932, Dallas Airmotive was one of the pioneers of engine repair and overhaul. Today, the company is the world's leading independent, OEM-authorzied turbine engine repair and overhaul company.

Company Name: Lockheed Martin Missiles and Fire Control – Dallas
Location: Dallas
Contact: Craig Vanbebber
Contact Email Address: craig.vanbebber@lmco.com
Company URL: www.missilesandfirecontrol.com
Description: Lockheed Martin Missiles and Fire Control develops, manufactures, and supports advanced combat systems including missile, rocket, and space systems.

Company Name: Lockheed Martin Space Operations*
Location: Houston
Contact: Sudhakar Rajulu
Contact Email Address: sudhakar.rajulu1@jsc.nasa.gov
Company URL: www.lockheedmartin.com
Description: Lockheed Martin Space Operations supports virtually every NASA mission that leaves the Earth, including those that explore deep space and other planets in the solar system. The company’s space-operations support includes developing and testing flight hardware, and conducting experiments for all of NASA's human spaceflight missions.

Company Name: Raytheon Aerospace Engineering Services
Location: Webster (Houston)
Contact: William Trump
Contact Email Address: william_e_trump@raytheon.com
Company URL: www.raytheon.com
Description: Raytheon is a leading prime contractor in defense and government electronics, space, information technology, technical services, and business aviation and special mission aircraft.

Company Name: Science Applications International Corporation (SAIC)
Location: Houston
Contact: Doug Weiss
Contact Email Address: Douglas.j.weiss@saic.com
Company URL: www.saic.com
Description: SAIC is a platform-independent provider of scientific, engineering, and systems integration services.

Biotechnology

Company Name: Bruker Optics*
Location: The Woodlands (Houston)
Contact: Scott Jacpuzynski
Contact Email Address: Scott.Japczynski@brukeroptics.com
Company URL: www.brukeroptics.com
Description: Bruker Optics is a leading supplier of spectrometer instrumentation equipment to the chemical refining and biotech industries in Texas.

Company Name: Lexicon Genetics*
Location: The Woodlands (Houston)
Contact: Walter “Skip” Colbert
Contact Email Address: SColbert@lexgen.com
Company URL: www.lexicon-genetics.com/index.php
Description: Lexicon Genetics is a drug discovery company. Their core competency is determining the functionality of genes to identify potential points of therapeutic intervention or pharmaceutical targets.

Company Name: University of Texas Medical Branch Galveston*
Location: Galveston
Contact: David Gorenstein
Contact Phone: (409) 772-2402
Company URL: www.utmb.edu
Description: Universities conducting biotech/biomed research such as the University of Texas, Baylor, Texas A&M, Texas Tech Health Science Centers, use quite a bit of high-speed automation equipment for experimental purposes.

Information and Computer Technology

Company Name: Dell
Location: Austin
Contact: Tom Holt
Contact Email Address: tom.holt@us.dell.com
Company URL: www.dell.com
Description: Dell is the world’s largest manufacturer of personal computers.

Company Name: Hewlett Packard
Location: Houston
Contact: Steve Ortmann
Contact Email Address: Steve.Ortmann@hp.com
Company URL: www.hp.com
Description: Hewlett Packard is the world’s largest manufacturer of printers. The company also manufactures desktops, laptops, digital cameras, and televisions.

Company Name: Intel
Location: Austin
Contact: Rito Martinez
Contact Email Address: rito.a.martinez@intel.com
Company URL: www.intel.com
Description: Intel is the world’s largest manufacturer of semiconductor chips. The company is also a leading manufacturer of computer, networking, and communications products.

Company Name: Nokia
Location: Dallas
Contact: Amit Kulkami
Contact Email Address: amitikd@yahoo.com
Company URL: www.nokia.com
Description: Nokia is the world’s largest manufacturer of mobile/wireless communication devices.

Company Name: Solectron
Location: Austin
Contact: Human Resources
Contact Phone: (512) 425-1000
Company URL: www.solectron.com
Description: Solectron provides a full range of electronics manufacturing and supply chain management services to the world’s leading networking, telecommunications, computing, consumer, automotive, industrial and medical device firms.
Petroleum Refining and Chemical Products

Company Name: Alcoa-Rockdale*
Contact: Charles Hoelscher
Contact Email Address: Charles.hoelscher@alcoa.com
Company URL: www.alcoa.com
Description: This 35,000-acre site is home to lignite mining, power generation, and aluminum smelting operations, ultimately producing the raw aluminum necessary for the manufacture of aluminum consumer and industrial products. At full capacity, the smelting plant, the largest in the United States, can produce two million pounds of aluminum per day.

Company Name: Bayer Material Science (Plastics)*
Location: Baytown (Houston)
Contact: Mike Buhr
Contact Email Address: mike.buhr@bayerbms.com
Company URL: www.bayermaterialsciencenafta.com
Description: Bayer Material Science is one of the largest producers of polymers and high-performance plastics in the world.

Company Name: British Petroleum
Location: Houston
Contact: John Payne
Contact Phone: (281) 366-7597
Company URL: www.bp.com/home.do?categoryId=1
Description: British Petroleum is a global energy company, employing over 96,000 people and operating in over 100 countries worldwide.

Company Name: Chevron Phillips
Location: Pasadena (Houston)
Contact: Ricci Wright
Contact Email Address: wrighrd@cpchem.com
Company URL: www.cpchem.com/enu/index.asp
Description: Chevron Phillips Chemical is one of the world’s top producers of olefins and polyolefins and a leading supplier of aromatics, alpha olefins, styrenics, specialty chemicals, piping, and proprietary plastics.

Company Name: Conoco Phillips*
Location: Sweeney
Contact: Alan Autenrieth
Contact Email Address: alan.autenrieth@conocophillips.com
Company URL: www.conocophillips.com
Description: Conoco Phillips is an international, integrated energy company. It is the third-largest integrated energy company in the United States, based on market capitalization, oil and gas proved reserves and production, and the second-largest refiner in the United States.

Company Name: Dow Chemical, Texas Operations
Location: Freeport
Contact: Richard Honea
Contact Email Address: rwhonea@dow.com
Company URL: www.dow.com
Description: Dow’s Texas Operations campus, located just south of Houston in Freeport, Texas, produces an estimated 100 chemical compounds and ships more than 1 billion pounds of chemical products every year.
Company Name: DuPont
Location: Victoria
Contact: Sheryl Marthiljohni
Contact Email Address: sheryl.marthiljohni@usa.dupont.com
Description: DuPont is a multinational chemicals company that offers a wide range of products and services for markets including agriculture, nutrition, electronics, communications, safety and protection, home and construction, transportation, and apparel.

Company Name: Eastman Chemical
Location: Longview
Contact: Roy Wiesner
Contact Email Address: rwiesner@eastman.com
Company URL: www.eastman.com
Description: Eastman is the world’s largest supplier of polyester plastics for packaging; a leading supplier of coatings raw materials, specialty chemicals, and plastics; and a major supplier of cellulose acetate fibers and basic chemicals. Eastman is one of the top 10 global suppliers of custom-manufactured fine chemicals for pharmaceuticals, agricultural chemicals, and other markets.

Company Name: ExxonMobil
Location: Houston
Contact: Ronald Baker
Contact Email Address: ronald.e.baker@exxonmobil.com
Company URL: exxonmobil.com/corporate
Description: ExxonMobil is an industry leader in almost every aspect of the energy and petrochemical business.

Company Name: Goodyear Beaumont Chemical Plant
Location: Beaumont
Contact: Steve Badon
Contact Email Address: lbad1@wt.net
Company URL: www.goodyear.com
Description: The Goodyear Beaumont Chemical Plant manufactures hydrocarbon resins, polybutadine & polyisoprene synthetic rubber compounds.

Company Name: Huntsman Chemical
Location: Port Arthur
Company URL: www.huntsman.com
Description: Huntsman is a global manufacturer and marketer of differentiated and commodity chemicals. The Port Arthur facility has an annual production capacity of 1.4 billion pounds of ethylene and 800 million pounds of propylene.

Company Name: Lyondell-Citgo Refinery
Location: Houston
Contact: Eddie Stiles
Contact Email Address: Eddie.Stiles@lyondell-citgo.com
Company URL: www.lyondell-citgo.com
Description: Lyondell-Citgo Refinery is one of the largest refineries in the United States. It is designed to process heavy, high sulfur crude oil. The facility covers nearly 700 acres along the Houston Ship Channel and has a rated capacity of approximately 268,000 barrels per day. The refinery manufactures petroleum products such as gasoline, diesel, heating oil, jet fuel, olefins feedstocks, aromatics, lubricants, and petroleum coke.
Company Name: Sherwin Alumina
Location: Gregory (near Corpus Christi)
Contact: Robert Walls
Contact Email Address: r cwalls@sherwinalumina.com
Company URL: www.sherwinalumina.com
Description: The primary function of the Sherwin plant is to extract aluminium oxide, called alumina, from bauxite ore. The plant is capable of producing 1.4 million tons of smelter grade alumina and 300,000 tonnes of chemical grade alumina hydrate per year.

Company Name: Valero Energy
Location: San Antonio
Contact: Claude Winslow
Contact Phone: (210) 246-3123
Company URL: www.valero.com
Description: Valero Energy is a Fortune 500 company based in San Antonio with approximately 22,000 employees and assets valued at $33 billion. The largest refinery in North America, Valero has an extensive refining system with a throughput capacity of approximately 3.3 million barrels per day.

Energy

This category includes three subclusters: oil and gas production, power generation and transmission, and manufactured energy systems.

Oil and Gas Production

Company Name: Anadarko Petroleum Corporation
Location: Houston
Contact: Human Resources
Contact Email Address: employment@anadarko.com
Company URL: www.anadarko.com
Description: Anadarko Petroleum Corporation is one of the world’s largest independent oil and gas exploration and production companies, with 2.37 billion barrels of oil equivalent (BOE) of proved reserves and a production of 190 million BOE in 2004.

Company Name: Chevron Pipe Line Company
Location: Houston
Contact: Human Resources
Contact Phone: (713) 432-3722
Company URL: www.chevron.com/products/prodserv/cpl/
Description: Chevron Pipe Line Company, headquartered in Houston, Texas, is a wholly owned subsidiary of Chevron Global Gas, which is ultimately controlled by Chevron Corporation. Chevron Pipe Line Company transports crude oil, refined petroleum products, liquefied petroleum gas, natural gas and chemicals within the United States. Volumes in the company’s network of approximately 13,000 miles of pipe reach nearly 2.2 million barrels per day.

Company Name: El Paso Corporation
Location: Houston
Contact: Human Resources
Contact Email Address: staffing@elpaso.com
Company URL: www.epenergy.com
Description: El Paso Corporation provides natural gas and related energy products. The company owns North America’s largest natural gas pipeline system and is one of North America’s largest independent natural gas producers.

Company Name: ExxonMobil
Location: Houston
Contact: Madhu Panchal
Contact Email Address: madhu.panchal@exxonmobil.com
Company URL: www.exxonmobil.com
Description: ExxonMobil is an industry leader in almost every aspect of the energy and petrochemical business.

Company Name: Hydraquip Corporation
Location: Houston
Contact: Anthony McGarvey
Contact Email Address: amcgarvey@hydraquip.com
Company URL: www.hydraquip.com
Description: Hydraquip is a full-line, stocking distributor of fluid power generating equipment serving Texas, Oklahoma, and Louisiana.

Company Name: Mustang Engineering
Location: Houston
Contact: Walt Hampton
Contact Email Address: walt.hampton@mustangeng.com
Company URL: www.mustangeng.com
Description: Mustang provides design, engineering and automation and control services for offshore and onshore oil and gas production facilities, refineries, and chemical plants.

Company Name: Plains Exploration and Production
Location: Houston
Contact: Human Resources
Contact Email Address: careers@plainsxp.com
Company URL: www.plainsxp.com
Description: Plains Exploration and Production is a leading independent oil and gas exploration company based in Houston. The company is primarily engaged in the activities of acquiring, developing, exploiting, exploring and producing oil and gas properties in the United States.

Company Name: ReedHycalog
Location: Houston
Contact: Larry Laughrun
Contact Email Address: larry.laughrun@reedhycalog.com
Company URL: http://www.reedhycalog.com
Description: ReedHycalog is involved in the design and manufacture of roller cone drill bits and synthetic diamond, PDC, and drill bits for the oil and gas industry.

Company Name: Shell
Location: Houston
Contact: Philip Carpentier
Contact Email Address: philip.carpentier@shell.com
Company URL: www.shell.com
Description: Shell is a global group of energy and petrochemical companies.
Company Name: Stress Engineering  
Location: Houston  
Contact: Clint Britt  
Contact Email Address: clint.britt@stress.com  
Company URL: www.stress.com  
Description: Stress Engineering Services is recognized as a leading expert in the oil and gas industry worldwide. The company offers design, testing, and analysis experience in both the upstream and downstream segments of the industry in virtually all phases of operations.

**Power Generation and Transmission**

Company Name: Austin Energy*  
Location: Austin  
Contact: Pat Alba  
Contact Phone: (512) 322-6523  
Company URL: www.austinenergy.com  
Description: Austin Energy is the nation’s 10th largest community-owned electric utility. It serves 360,000 customers and a population of more than 800,000. The utility provides service within the City of Austin, Travis County, and a small portion of Williamson County.

Company Name: Center Point Energy  
Location: Houston  
Company URL: www.centerpointenergy.com  
Description: Subsidiaries distribute electricity and natural gas to primarily the southern United States, and generate electricity. Also operates gas pipeline.

Company Name: City Public Service  
Location: San Antonio  
Contact: Human Resources  
Contact Phone: (210) 353-2251  
Company URL: www.citypublicservice.com  
Description: City Public Service Energy is the nation’s largest municipally owned energy company providing both natural gas and electric service. Acquired by the city of San Antonio in 1942, CPS serves more than 640,000 electric customers and more than 310,000 natural gas customers in and around San Antonio.

Company Name: El Paso Electric Company  
Location: El Paso  
Contact: Human Resources  
Contact Phone: (915) 543-5711  
Company URL: www.epelectric.com  
Description: El Paso Electric generates and distributes electricity through an interconnected system to approximately 344,000 customers in the Rio Grande Valley in west Texas and southern New Mexico.

Company Name: Lower Colorado River Authority*  
Location: Austin  
Contact: Roy West  
Contact Email Address: roy.west@lcra.org  
Company URL: www.lcra.org  
Description: LCRA plays a variety of roles in Central Texas: delivering electricity, managing the water supply and environment of the lower Colorado River basin, developing water and...
wastewater utilities, providing public recreation areas, and supporting community and economic development.

Company Name: TXU Power*
Location: Dallas
Contact: Thomas Johnston
Contact Email Address: wade.johnston@hewitt.com
Company URL: www.txucorp.com
Description: TXU Energy markets electricity and related services to customers throughout Texas.

Instrumentation/Automation Companies

This is not one of the Governor’s Industry clusters but the activities of instrumentation/automation manufacturers and users will be important to mechatronics employment in the state.

Company Name: ARM Automation*
Location: Austin
Contact: Derek Black
Contact Email Address: dblack@armautomation.com
Company URL: www armautomation.com
Description: ARM builds, designs, and integrates automation systems. Industries served include semiconductor manufacturing, medical equipment production, electronic test and packaging, metal fabrication, hazardous materials handling, food packaging and inspection, automotive manufacturing, and plastics injection modeling.

Company Name: The Eads Company*
Location: Dallas
Contact: Bobby Brooks
Contact Email Address: bbrooks@eadslink.com
Company URL: www.eadslink.com
Description: The Eads Company provides products and services, including instrumentation equipment, to the chemical, petrochemical, refining, energy, OEM, research and development, and power industries.

Company Name: Entech Sales and Services*
Location: Austin
Contact: Robert Emmert
Contact Email Address: remmert@entechsales.com
Company URL: www.entechsales.com
Description: Entech is a systems integrator of building automation, security, access, closed circuit television systems, and HVAC systems.

Company Name: Hydraulic Works*
Location: Bryan
Contact: Van Goerger
Contact Email Address: van-hwi@verizon.net
Company URL: hydworks.com
Description: Hydraulic Works is a full-service company focusing on hydraulic and pneumatic sales, design, repair, and rebuild of a wide variety of hydraulic and pneumatic type control systems.

Company Name: Johnson Controls*
Location: Irving
Contact: Dean Richman  
Contact Email Address: dean.j.richman@jci.com  
Company URL: www.jci.com  
*Description:* Johnson Controls (Irving) specializes in the engineering, installation, and servicing of building management systems.

**Company Name:** Wilson Company*  
**Location:** San Antonio  
Contact: Rick Porter  
Contact Email Address: rporter@wilson-company.com  
Company URL: www.wilson-company.com  
*Description:* Wilson Company provides a wide variety of hydraulic, pneumatic, and fluid connector products and services for their customers.

**Company Name:** Yokogawa Corporation of America*  
**Location:** Sugar Land (Houston)  
Contact: Pete Dibello  
Contact Email Address: pete.dibello@us.yokogawa.com  
Company URL: www.yokogawa.com/us  
*Description:* Yokogawa is a world leader in industrial automation and control, test and measurement, information systems, and industry support.
Appendix E: Select K-12 Mechatronics Programs

World Skills International Mechatronics Olympics

The challenges presented in the World Skills competition are designed to simulate actual industry systems and problems. In fact, modular production systems and components from industrial mechatronic manufacturers are used in the competition. Additionally, during the course of the competition students must exercise a number of soft skills, such as the ability to work in a team, that they will ultimately have to demonstrate in a work environment (Festo, 2006). www.worldskills.org

SkillsUSA

The SkillsUSA Mechatronics program requires contestants to understand the new industrial discipline of “mechatronics,” the ability to understand complex systems that integrate various elements in the mechanical, fluid power, and controls domain, combined with the ability to work in a team environment with people of different areas of expertise. Mechatronic specialists must therefore have well development skills in pneumatic technology, electrical and electronics systems, mechanical systems and general automation techniques and practices, including systematic troubleshooting methods. This competition consists of three events designed to measure the skills required in the modern automated manufacturing environment. www.skillsusa.org

US FIRST

The FIRST Robotics Competition challenges teams of young people and their mentors to solve a common problem in a six-week timeframe using a standard “kit of parts” and a common set of rules. Teams build robots from the parts and enter them in a series of competitions designed by Dean Kamen, Woodie Flowers, and a committee of engineers and other professionals. The competition has grown to 1,125 teams competing in 33 Regional Events, and The Championship held at the Georgia Dome in Atlanta where more than 8,500 high-school-aged young people participate. FIRST redefines winning for these students. Teams are rewarded for excellence in design, demonstrated team spirit, gracious professionalism and maturity, and ability to overcome obstacles. Over 80,000 middle-school students in 34 countries will explore nano-mechatronics by building robots that simulate nano systems as part of the NanoQuest 2007 First Lego League. www.usfirst.org

Botball

The Botball Educational Robotics Program integrates science, technology, engineering, and math with robotics for middle school, high school, CTCs and Universities. Students are given about seven weeks to design, build, and program a team of mobile, autonomous robots and a website documenting their process.
Participants compete against each other on a 4’ x 8’ playing field in a fast paced, non-destructive tournament. The robots are student built and programmed to maneuver on the game board without the need for remote control. Each year students, teachers, robotics enthusiasts, and professionals from across the country gather for the Regional Conference on Educational Robotics and the National Conference on Educational Robotics. www.botball.org

**BEST**

BEST features two parallel competitions: (1) A robotics game, which is based upon an annual theme with four teams competing at once in a series of three-minute, round-robin matches and (2) The BEST Award, which is presented to the team that best embodies the concept of Boosting Engineering, Science, and Technology. Elements include a project summary notebook, oral presentation, table display, and spirit and sportsmanship. Each school is provided kits of equipment and parts, a set of game rules, and given six weeks to design, build, and test a small Radio/Controlled (R/C) robot that outperforms other robots. www.bestinc.org/MVC/

**EARLY**

Engineering And Robotics Learned Young (EARLY) is a program that exposes young people to engineering. EARLY provides 7-to-12 year old children the opportunity to participate in a robotics competition during the fall and spring. EARLY competition robots are built from LEGO® Simple Machines kits. EARLY team members have a bright future with the opportunity to participate, throughout their education careers, in various robotics competitions such as FIRST LEGO® League, Botball, BEST, and the FIRST Robotics Competition. www.earlyrobotics.org

**Science Olympiad**

Science Olympiad mission is to create a passion for learning science by supporting elementary and secondary Science Olympiad tournaments at building, district, county, state and national levels with an emphasis on teamwork and a commitment to excellence. We seek to improve the quality of K-12 science education throughout the nation by changing the way science is perceived and the way it is taught (with an emphasis on problem solving and hand-on, minds-on constructivist learning practices). www.soinc.org

**Project Lead the Way**

Project Lead the way is a partnership with our nation’s schools to prepare an increasing and more diverse group of students to be successful in science, engineering, and engineering technology. Project Lead the Way provides inclusive opportunities for all academically qualified students without regard to gender or ethnic origin. We aim to reduce the future college attrition rate with four and two-year engineering and engineering technology programs. www.pltw.org
**Micromouse**

The Global Micromouse championship is an international robotics competition held every year in the UK since 1980. Similar events are also held in the USA, Japan, Singapore, Korea and elsewhere. Autonomous robot ‘mice’ race against the clock to search the centre of a maze in the shortest time. The competition is open to all-comers, and would-be mouse builders or interested spectators are also welcome. Beginners might like to enter the wall follower category first and then progress to the full micromouse maze solving competition later. There is an increasing amount of practical mouse building information being placed on the web. The ‘Links’ page points to some good sites. [http://micromouse.cannock.ac.uk](http://micromouse.cannock.ac.uk)

**fischertechnik**

fischertechnik® is the flexible construction system for young and older system designers alike. Produced in Germany to high standards, these robot kits allow a multitude of systems and 3D models to be created by slotting precision-engineered parts together. Although the robot kits are designed to be easy to use, they can be utilized to learn and teach advanced concepts in engineering, robotics, PLC or computer control. As a matter of fact, fischertechnik is very popular with many of the leading technology educators in the United States and across the globe. Created by one of Europe’s leading manufacturers of industrial connectors, fischertechnik has now been innovating and manufacturing the world’s most advanced robotics modeling systems since 1965. [www.fischertechnik.com](http://www.fischertechnik.com)

**Terk**

TeRK, stands for Telepresence Robot Kit, is a project of the Community Robotics, Education and Technology Empowerment (CREATE) Lab at Carnegie Mellon University’s Robotics Institute. Our aim with TeRK is to make educational robotics fun, affordable, and accessible to a diverse community of college students, pre-college students, and all individuals interested in robotics. TeRK builds upon the success of our previous project, the Personal Rover Project. [www.terk.ri.cmu.edu](http://www.terk.ri.cmu.edu)

**Qwerk**

Qwerk is a powerful embedded computer system with an I/O feature set specifically targeted for robotics and mechatronics applications. Qwerk has a powerful CPU that can run a modern OS such as Linux or Windows CE and is capable of hosting sophisticated applications that require high-level programming, multitasking, Internet connectivity and networking. This guide details the hardware features, connector pinouts, and peripheral specifications of Qwerk. [www.charmedlabs.com](http://www.charmedlabs.com)
Microsoft Robotics Studio

Microsoft® Robotics Studio, a new Windows®-based development environment for creating robotic software for a wide variety of hardware platforms. Microsoft also introduced a new third-party partner program featuring Microsoft Robotics Studio-enabled applications, services and robots from independent software vendors, service providers, hardware component vendors and robot manufacturers. Already more than 30 third-party companies have pledged support for the new robotics development and runtime platform, which is available for download and evaluation at www.microsoft.com/robotics.

VexLABS

Innovation First incorporated in 1996 and is a privately held S corporation. The company is founded on the belief that innovation very early in the design process is necessary to produce simple and elegant designs. Innovation first began producing electronics for unmanned mobile ground robots, and is now the industry leader. www.vexlabs.com

Institute for Personal Robotics Education

The Institute for Personal Robots in Education (IPRE) applies and evaluates robots as a context for computer science education. IPRE is a joint effort between Georgia Tech and Bryn Mawr College sponsored by Microsoft Research. At Georgia Tech, IPRE is associated with Robotics and the College of Computing. At Bryn Mawr College, IPRE is associated with the Computer Science Department. www.roboteducation.org

Hobby Engineering

Hobby Engineering has tools, gadgets and systems that enable students to experience the process of building electronic gadgets and robots. A hobby store for those who love to build. www.hobbyengineering.com

SPYKE - New Consumer Educational Robot

- Spy robot—Spyke moves, watches, speaks and listens
- VOIP phone—Use your Spyke as a wireless VOIP phone (compatible with Skype 3.0 PC technology)
- Digital Music Player—listen to your own music over Wi-Fi with Spyke
- Video Surveillance—When a movement is detected, Spyke activates an alarm on your computer or sends you a picture by email
- Other play functions include snapshot, sound and video recording, light, voice and sound effects and video filters

- Wi-Fi card included

- Motion sensors activate automatically when something happens

Source: www.gizoo.co.uk/Products/ToysGames/RadioControl/MeccanoSpykeRobot.htm
www.spykeworld.com

- Returns to recharging station automatically when battery is low

- Control on local Wi-Fi connection or remotely on internet
Bibliography


Mechatronics A Technology Forecast
Implications for Community & Technical Colleges in the State of Texas

Mechatronics is another way of saying “intelligent mechanical systems” and it is the foundation of many 21st century enabling technologies and careers. Mechatronics involves the integration of mechanical and electrical systems with control systems and information technology.

Mechatronic products and processes are increasingly pervasive across a broad range of industries. These same industries are expressing a clear demand for highly skilled employees capable of excelling in these technologically advanced environments and competent in the multi-disciplinary application of technologies associated with mechatronics. Colleges should respond to these employer demands by updating curriculum and creating new courses and programs to serve this emerging technology workforce need.

The analysis and information resources provided in this report will aid colleges in developing Mechatronic programs and certificates. This publication includes an overview of mechatronic technology and analysis of related occupations and salaries, inventory of existing mechatronic curriculum and considerations for colleges considering developing related programs and lists of industry experts and mechatronics companies.

TSTC Emerging Technologies
Texas State Technical College Emerging Technology identifies emerging technology trends, evaluates potential workforce implications and recommends new courses and programs for two-year colleges in Texas. This program helps to ensure Texas employers continue to have the highly skilled workforce necessary to compete in an increasingly global and technologically complex marketplace. Visit www.forecasting.tstc.edu for more information about this program and additional TSTC Emerging Technologies publications.

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