

## **CORE COMPETENCY NEEDS IN MATERIALS TECHNOLOGY**

Robert L. Mott <sup>1,2</sup>, Thomas G. Stoebe <sup>3,4</sup>, Robert Simoneau <sup>4,5</sup> and Imelda Cossette <sup>4,6</sup>

<sup>1</sup> University of Dayton, 300 College Park, Dayton, OH 45469; <sup>2</sup> National Center for Manufacturing Education, Sinclair Community College, 444 West Third St., Dayton, OH 45402; <sup>3</sup> University of Washington, Seattle, WA 98195; <sup>4</sup> National Resource Center for Materials Technology Education, Edmonds Community College; <sup>5</sup> Keene State College, 229 Main St., Keene, NH 03435; <sup>6</sup> Edmonds Community College, 20000 68th Ave. West, Lynnwood, WA 98036.

### **ABSTRACT**

Industry focus groups have developed a set of materials-related competencies for workers in manufacturing and engineering. Focus group participants were engineers from cross sections of American industry. Results include specifics on essential topics that need to be included in manufacturing, engineering and materials curricula. While the study is focused on the technician level, many of the results are clearly applicable to the engineering level as well.

The study confirms the vital place of communication, measurement, mathematics, computer skills and teamwork skills within the scope of today's workers. In addition, the study demonstrates the need for all workers to understand that any change in a manufacturing process will affect materials properties, and that such change in process can and will change the properties of the product. This was rated as more important than the understanding of most specific processes or properties. Nearly as important was to understand the effects of operator and equipment variations on test results. Other areas included testing processes, mechanical and electronic properties, fabrication processes, tooling and manufacturing operations. Ability to recognize and address quality and safety issues was rated as essential. Essential details of the study are presented in this manuscript; full details are provided in the full report, available on the National Resource Center for Materials Education web site.

**Key words:** *core competencies, materials education, curriculum*

### **INTRODUCTION**

Twenty-first century production systems require engineers and technicians with multiple skills able to deal with a range of advanced technologies. New materials and process

technologies, from advanced composites to nanotechnology, will play an increasingly important role in manufacturing process improvement as advanced materials are integrated into new and existing manufacturing systems and products.<sup>1-3</sup> Many reports have

discussed the current problems with the manufacturing workforce in the U.S.<sup>2, 4-9</sup> Materials technologies are an important component of our overall manufacturing base, and high performance materials have been noted as one of the 20 greatest engineering achievements of the 20th century.<sup>9</sup>

In addition to an understanding of new materials, a thorough education in materials fundamentals is also required, as indicated in this study. Core competencies in the broad area of materials technology are needed to define the materials-related skills a worker needs in today's advanced manufacturing environment. The determination of core competencies is also required before needed targeted curricula can be deployed. The availability of appropriate curricula will assure that workers are trained in both the fundamental competencies as well as in those needed for the new technological materials that they will be dealing with in the future.

Listings of core competencies in the area of manufacturing<sup>10,11</sup> are available and do include a general focus on materials topics. These topics include joining, shaping, casting and molding of plastics, metals, composites and other engineering materials in electronic and structural applications. However, no specific set of competencies in materials technology has been published.

This core competency research is an important component of the development of MatEd, the National Resource Center for Materials Technology Education.<sup>12</sup> The goals of MatEd include developing a broad collection of materials-based curricula, and the creation of a specific set of curriculum modules aimed at assisting faculty in teaching the core competencies. MatEd's resources will include curriculum modules, classroom demonstrations and appropriate laboratory exercises, which will be available on the internet for widespread faculty use.

This study focuses on competencies in materials technologies, with an emphasis on the

technician level. Competencies are identified for the general manufacturing technician as well as those skills needed for technicians in specific areas requiring additional materials understanding, such as materials testing labs. In reviewing the results, it is clear that many of the competencies identified in the materials-specific areas are equally applicable to engineers, including both materials engineers and other engineers who handle materials in design and manufacture.

## PROCEDURES

Four focus groups were arranged for industrial personnel from a variety of industries in four cities in the U. S., Seattle, Los Angeles, Detroit and Cleveland. The choice of cities was an attempt to ensure coverage of as broad a set of industries as possible. A total of 35 participants included engineers, engineering managers and technicians at 27 different companies, plus others with experience in manufacturing not currently employed in industry.

The authors developed an initial list of 250 potential competencies in 19 major categories, as follows:

- a) Four categories involved general technical, employability, and professionalism skills
- b) Three focused on mathematics, chemical science, and physical science skills
- c) Two dealt with fundamentals of materials technology and materials testing
- d) Seven related to different classes of materials and their processing. These classes contained nine sub-categories to break out specific types of materials.
- e) Three related to manufacturing processes, tooling, and their effects on the mechanical properties of materials

This list of 250 competencies was rated by each of the participants. During this process, participants were asked to add to the list of competencies, and at the end a total of 397 competencies had been developed. Since some

of these new competencies were added after the initial focus group meetings, all participants were subsequently asked to rate those added after their group meeting. The focus group participants were asked to rate all of the competencies as they related to their own industry and organization. Two ratings were requested;

- For the **Materials Technician** whose primary job tasks relate directly with the processing or testing of materials.
- For the **General Technician** engaged in technical work but who does not have direct responsibility for materials processing.

The rating scale used was 1= vital; 2 = important; 3 = desirable but not critical; and 4 = not important. Using this rating scale, a merged set of competencies was developed for further analysis.

## RESULTS

To facilitate our review of the competencies identified as most important in this study, competencies were divided into a subset of 75 competency categories. These categories are used here to set out the general tone of the competency results. Where there are specific competencies within these competency categories that provide additional information on the most important competencies, these are also presented. Results are presented, as appropriate, for both the general and the materials technician. The reader should note in each case the difference between the competency categories, in which ratings for a set of competencies are aggregated, and any mention of the competencies themselves, which are the components of the categories.

Complementary to this manuscript, the full set of competency results is available on the Internet, as are the details of the subset of 75 competency categories, at [http://www.materialseducation.org/competencies\\_report.html](http://www.materialseducation.org/competencies_report.html). In

this manuscript, we will set forth the most significant of the results, using both competency categories and the most important specific competencies.

For all classes of technicians, basic competencies rated in the important/vital range included communication, testing and data analysis, workplace performance and general technical competence. Also of importance, were measurement and basic technical skills, mathematics, computer skills and teamwork and professionalism. Table 1 shows the competency category mean rating values for these and related items for both general and materials technicians. Noting that 1 is the highest rating (“vital”), while 2 is “important,” most of these categories may certainly be deemed “important” for all classes of technicians. It should be noted that among these categories, the areas identified as most important were communication, basic mathematics and general computer skills. Measurement of dimensions and physical phenomena were also noted as important for materials technicians.

Looking more specifically at the individual competencies included in the categories in Table 1, a number of specific individual competencies were rated in the “vital” range, taken here as a rating <1.2. These included the following for both general and materials technicians, with the highest rating (lowest value) listed first:

- Follow directions from supervisors and request additional information as needed (ref. 0.004)
- Practice good workplace safety methods (ref. 0.017)

For materials technicians, the following also were rated <1.2:

- Measure accurately dimensions using scales, micrometers, vernier calipers, etc. (ref. 1.001)

Table 1. Competency ratings for both General Technicians and Materials Technicians for general basic competency categories. Results are based on the reduced set of competency categories. Each table represents categories containing the indicated number of specific competency ratings, "no. items." Scores listed are means for all items in the listed category. For the specific competency ratings themselves, the reader should refer to the reference number noted within the full set of competencies, available elsewhere.<sup>12</sup>

<b>Table 1</b>				
<b>Ref.</b>	<b>Competency</b>	<b>No. items</b>	<b>Gen tech</b>	<b>Mtls tech</b>
0.000	Basic competencies related to work as a technician			
	Communication	9	1.86	1.74
	Testing and data analysis	3	2.02	1.40
	Workplace performance	13	1.86	1.73
	General technical competence	5	1.92	1.83
1.000	Measurement and basic technical skills			
	Measurement of dimensions and physical phenomena	14	2.27	1.75
	Working with technical drawings	3	2.19	2.20
	Laboratory skills	8	2.38	1.85
	Working with sensors and electrical phenomena	8	2.63	2.55
2.000	Mathematics, calculations, and data analysis			
	Basic mathematics fundamentals	4	1.68	1.47
	Proper use of units and conversions	4	1.84	1.58
	Geometry and trigonometric fundamentals	3	2.30	1.85
	Algebra and functions	4	2.76	2.33
	Statistics	4	2.43	2.03
3.000	Computer skills			
	General computer skills and practices	4	1.79	1.68
	Computer applications in the office and laboratory	5	2.29	1.88
	Technical software applications	3	2.84	2.51
4.000	Teamwork, professionalism, globalism, and multiculturalism skills			
	Working effectively in teams	3	1.58	1.70
	Understanding project interactions	4	2.88	2.71
	Personal professionalism	8	1.95	1.87
	Cultural awareness in the workplace	2	2.23	2.18
	Globalism	3	3.01	2.92

Rating scale: 1 = vital; 2 = important; 3 = desirable; 4 = not important

- Measure accurately hardness, impact strength and related properties of materials (ref. 1.004)

Here, reference is made to the original competency listing number to allow the reader to locate the specific reference in the full report.

Evaluating the importance of chemical and physical science skills begins to differentiate

the general from the materials technician in terms of needed competencies. Table 2 demonstrates this difference, with aggregate category ratings for the materials technician showing significantly more importance than those for the general technician, especially in chemical skills. Reviewing specific competencies in the chemical and physical science area, the specific ratings in this area were not seen to be as vital as those in the

Table 2. Competency ratings for both General Technicians and Materials Technicians for chemical and physical science skills, based on the reduced set of competency categories, as in Table 1.

<b>Table 2</b>				
<b>Ref.</b>	<b>Competency</b>	<b>No. items</b>	<b>Gen tech</b>	<b>Mtls tech</b>
5.000	Chemical Science Skills			
	Safety and environmental issues	5	1.96	1.78
	Chemistry fundamentals	11	2.74	1.90
	Nuclear applications	2	3.40	2.80
6.000	Physical science skills			
	Mechanics	9	2.60	2.40
	Fluid and thermal concepts	3	2.69	2.06
	Electricity and magnetism	3	2.90	2.68
	Light and sound	2	2.87	2.77

Rating scale: 1 = vital; 2 = important; 3 = desirable; 4 = not important

section above, with ratings more in the range 1.5 – 3. The specific competencies rated most important for all technicians (rating < 1.6) were:

- Safely apply information from Material Safety Data Sheets (MSDS) (ref. 5.005)
- Safely handle acids, bases, flammable liquids, cryogenic fluids and compressed gases (ref. 5.004)

For the materials technician, additional competencies were also rated <1.6:

- Apply knowledge of chemical and environmental safety, including waste disposal and recycling (ref. 5.003)
- Read basic chemical abbreviations for compounds (ref. 5.007)
- Demonstrate knowledge of chemical symbols and the periodic table (ref. 5.006)
- Apply correctly appropriate units for physical quantities (ref. 6.008)

Competency categories in basic materials science and technology are summarized in Table 3. Here, the data indicate that the materials technician needs a number of

competencies that are of lesser importance to the general technician. Specifically, understanding and being able to measure stress and strain were the highest rated topics for the materials technician in this category (rating <1.5, with lowest rating first):

- Define strain (ref. 7.018)
- Define stress (ref. 7.017)
- Define and compare the behavior of ductile and brittle materials (ref. 7.021)
- Define ultimate tensile strength (ref. 7.028)

Other competencies in this area rated <1.6 include defining the ultimate compressive strength, the modulus of elasticity, and ductility. Also rated in this range was “Describe how polymers differ from metals, glasses and ceramics and how this affects properties.”

Materials testing competency categories cover a wide range of topics, as is also noted in Table 3. Since this is usually a principal job for a person who would be classified as a materials technician, it is not surprising that many of the categories are rated at 2 or less. Indeed, no less than 17 specific competencies are rated <2 for materials technicians. The

Table 3. Competency ratings for both General Technicians and Materials Technicians for skills related to the fundamentals of materials science and technology and for materials testing, based on the reduced set of competency categories, as in Table 1.

<b>Table 3</b>				
<b>Ref.</b>	<b>Competency</b>	<b>No. items</b>	<b>Gen tech</b>	<b>Mtls tech</b>
7.000	Fundamentals of materials science and technology			
	General nature of metals	4	2.69	1.79
	General nature of plastics	3	2.70	2.00
	General nature of composites	2	2.98	2.24
	General nature of semiconductors and optical materials	3	3.04	2.51
	General nature of ceramics and glasses	2	2.91	2.20
	Other materials	2	3.11	2.61
	Stress and strength	9	2.56	1.70
	Strain and deformation	10	2.53	1.58
	Analysis of material structure	4	2.56	1.96
	Design considerations	7	2.71	2.03
	Thermal, physical, and other properties of materials	3	2.62	2.07
	Plastics and polymers	2	2.76	2.03
	Emerging materials technologies	4	3.17	2.96
8.000	Materials testing			
	Experimental planning and execution	5	2.62	2.03
	General mechanical testing processes for solid materials	9	2.84	1.60
	Visual and nondestructive testing	8	3.11	1.95
	Working with standards	4	2.99	2.21
	Testing metallic materials	1	2.71	1.44
	Testing plastics and composites	7	3.21	2.20
	Testing of wood and concrete	2	3.48	2.51
	Testing of liquids	5	3.29	2.65

Rating scale: 1 = vital; 2 = important; 3 = desirable; 4 = not important

highest rated are (rating < 1.6, with lowest rating first):

- Describe the types of material properties found from a tensile test (ref. 8.002)
- Describe the fundamentals of performing a tensile test on a metallic material (ref. 8.001)
- Perform tensile tests for a variety of materials (ref. 8.005)
- Describe several methods of measuring hardness of materials (ref. 8.004)
- Perform hardness tests for a variety of materials (ref. 8.007)
- Perform impact tests for a variety of materials (ref. 8.006)

- Describe the measurement of impact strength using the Charpy and Izod methods (ref. 8.003)

Other specific competencies highly rated in this area for materials technicians (<1.7) include demonstrating basic knowledge of micro-hardness measurements and of hardness profiles, and the ability to prepare a material specimen for metallurgical analysis.

Competency categories related to specific materials are given in Table 4 with mean ratings for each category. Describing the constituents, properties and property changes with processing were rated most important with

Table 4. Competency ratings for both General Technicians and Materials Technicians for materials and processing for metals, plastics, composites, wood, concrete glasses and ceramics, based on the reduced set of competency categories, as in Table 1.

<b>Table 4</b>				
<b>Ref.</b>	<b>Competency</b>	<b>No. items</b>	<b>Gen tech</b>	<b>Mtls tech</b>
9.000	Materials and processing - Metals			
	Steel	15	2.95	1.84
	Cast iron	2	3.00	2.13
	Aluminum	7	3.11	2.12
	Copper and its alloys	2	3.18	2.16
	Zinc and its alloys	1	3.17	2.26
	Magnesium and its alloys	2	2.88	2.19
	Nickel alloys (Superalloys)	4	3.17	2.23
	Titanium and its alloys	2	2.89	2.21
10.000	Materials and processing - Plastics			
	Thermoplastics	11	2.98	2.17
	Thermoset plastics	6	3.05	2.42
11.000	Materials and processing - Composites			
	Nature of composite materials	9	2.78	2.18
	Processing of composite materials	14	2.99	2.82
12.000	Materials and processing - Wood	3	3.19	2.83
13.000	Materials and processing - Concrete	3	3.21	2.69
14.000	Materials and processing - Glasses	11	3.29	2.61
15.000	Materials and processing - Ceramics	7	3.19	2.55

Rating scale: 1 = vital; 2 = important; 3 = desirable; 4 = not important

steels, followed by other metals, plastics, composites, ceramics, glasses, concrete and wood. Of all the categories, this one reflects most on the sources of data, that is, the companies and materials that are most important in those companies in which the focus group participants work. Trends here are well represented by the category ratings in Table 4.

The final area for which competencies were reviewed is the area of processing and manufacturing. Competency categories in this area are given in Table 5 with mean ratings for

each. For BOTH general and materials technicians, the following specific competencies were rated <1.6:

- Describe how changes in manufacturing processes affect material properties (ref. 16.007)
- Recognize and address quality and safety issues (ref. 19.013)

Related to the latter for the general technician was the specific competency from an earlier section (rated 1.58):

Table 5. Competency ratings for both General Technicians and Materials Technicians for relationships between processing variables, fabrication, tooling and manufacturing operations, based on the reduced set of competency categories, as in Table 1.

<b>Table 5</b>				
<b>Ref.</b>	<b>Competency</b>	<b>No. Items</b>	<b>Gen tech</b>	<b>Mtls tech</b>
16.000	Relationships between processing variables, quality, material properties, defects			
	Effects of processing and manufacturing variations on material properties	4	2.20	1.60
	Effects of defects on material properties	4	2.55	1.89
17.000	Fabrication, machining, fastening, welding, forming, forging, finishing, etc.			
	General processes	7	2.40	2.13
	Metals processing	6	2.31	1.93
	Processing of plastics and composites	2	2.25	1.97
18.000	Tooling, dies, jigs, fixtures			
	General tooling practices	2	2.77	2.71
	Tooling for metal processing	6	2.29	2.14
	Tooling for plastics and composites processing	4	2.63	2.45
19.000	Manufacturing operations and quality management			
	Quality management	6	2.00	1.99
	Manufacturing operations management	12	2.67	2.75

Rating scale: 1 = vital; 2 = important; 3 = desirable; 4 = not important

- Determine effects of variations due to operator, machine or material (ref. 8.044)
- Describe how defects such as nicks and scratches affect properties of metals and alloys (ref. 16.003)

Clearly these and a variety of related competencies are deemed important for the general technician.

For the materials technician, other specific competencies in this area rated highly (<1.7) include:

- Describe how cold working affects the mechanical properties of metals (ref. 16.002)
- Describe how heat treating affects the mechanical properties of metals (ref. 16.001)

In the processing areas, both general technician (rating 1.89) and the materials technician (rating 2.00) were expected to be able to describe several kinds of cutting tools used for machining metals. For materials technicians, a specific competency to describe several types of forming, casting and molding processes for metals, and one on understanding how surface finishes of machined metals affect properties were rated <1.8. In manufacturing, the ability to differentiate between critical and non-critical defects was rated 1.82 for the materials technician and 2.00 for the general technician.

## DISCUSSION

These data indicate that there are two essential areas for all technicians to understand, with “essential” being interpreted here as ratings between 1.0 and 1.9 in the analysis above. One essential area relates to communication and related teamwork and professional skills, along with an understanding of quality and safety issues. The other is an understanding of the fundamental relationship between processing and properties of materials.

Considering first the fundamental relationship between processing and properties for all technicians, the description of how changes in manufacturing processes affect material properties was rated at 1.58 for the general technician and at 1.50 for the materials technician. This corroborates a variety of anecdotal input relating to the problem of unreported changes in processes affecting a product. Also in this category are effects of variations due to operator, machine or materials, rated at 1.58 for the general technician, and 1.82 for the materials technician. Clearly, this area is a vital part of education in the manufacturing and engineering areas, probably not just for technicians but also for engineers.

The other essential area for all technicians is communication (average rating of 1.86 for the general technician, 1.74 for the materials technician). The ratings indicate that all technicians must also practice good attendance, be able to follow directions and work in teams, perform basic math skills including being conversant with units and conversion, and have good general computer skills. Understanding safety and environmental issues are also essential for all technicians.

These basic skills clearly must be included in any quality educational program for technicians. Other core competencies rated highly in this study have been noted in the previous section. The key is to find means whereby these materials-related skills can be taught in all technician programs. In many

cases, faculty members in manufacturing or engineering programs have little expertise in materials-related areas of competency. Often, this means that the materials-related competencies are not taught. One goal of MatEd is to provide modules to faculty to allow them to include these important competency areas in their course curricula.

For the materials technician, a variety of other items are rated as essential. These include:

- Testing (both destructive and non-destructive) and data analysis
- Laboratory skills
- Chemical fundamentals including dealing with abbreviations and concentrations
- Applying appropriate units
- Describing stress, strength, strain, deformation
- Analysis of material structure
- Describing processing techniques for metals, plastics and composites

A general understanding of mechanical and electronic properties of various materials classes, knowledge of general fabrication processes, tooling and manufacturing operations were also highly rated. An ability to recognize and address quality and safety issues was rated as essential.

These latter competencies include more of the properties/processing/structure relationships that are basic to the materials profession and that affect the performance of the product. Materials technicians in processing, joining, testing and related areas must be conversant with these competencies, and educational programs need to include the basics as well as applications related to these concepts. These needs apply to engineers as well.

One observation by the authors in reviewing these data is that it appears that the industrial raters had a low expectation of their technicians in areas such as mathematics, chemistry and physical sciences. This may be due to poor technician education in the past. It is important to raise this bar and to improve both

educational programs and the competencies of technicians to better meet the needs of our industries today.

These competency ratings were developed with representation from a wide variety of materials-related industrial personnel. However, due to the small sample size and the absence of representations from evolving materials-related industries, this set of competencies cannot be considered complete. It is also the case that some lower rated competencies can be quite important in certain industries. From this point of view, this study provides a starting point for the determination of basic competencies that are essential in technology education. The authors welcome further elaboration on competencies in the materials area.

#### ACKNOWLEDGEMENTS

The authors wish to thank Drs. John Rusin and Laura Collins for their input on this manuscript, along with the more than 40 individuals who participated in this study. This project was sponsored by MatEd, the National Resource Center for Materials Technology Education, headquartered at Edmonds Community College, Lynnwood, WA. The National Resource Center is supported by the National Science Foundation under Advanced Technological Education grant DUE-0501475. The opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not reflect the position or policies of the National Science Foundation.

#### REFERENCES

1. *Visionary Manufacturing Challenges for 2020*, Committee on Visionary Manufacturing Challenges, National Academy Press, p. 11-12, 1998.
2. *Industrial Transformation: Key to Sustaining the Productivity Boom*, National Coalition for Advanced Manufacturing, 2003.
3. *Materials Science and Engineering: Forging Stronger Links to Users*, Committee on Materials Science and Engineering, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, 1999.
4. *The Case for Enhancing American Workforce Skills*, National Coalition for Advanced Manufacturing, 2003;
5. "Manufacturing Skills Crisis: Solutions to this National Challenge", National Coalition for Advanced Manufacturing, 2003.
6. "Failure is Not an Option," Dr. Craig Barrett, CEO, Intel Corp., in *Profiles of Excellence in Business and Education Leadership*, National Alliance of Business, 2001.
7. "Losing our Edge?," Thomas L. Friedman, *New York Times*, April 22, 2004.
8. *Keeping America Competitive; How a Talent Shortage Threatens U.S. Manufacturing*, National Association of Manufacturers, 2003
9. "Greatest Engineering Achievements of the 20th Century," National Academy of Sciences, 2000.
10. *Manufacturing Skill Standards*, Manufacturing Skills Standards Council, National Coalition for Advanced Manufacturing.
11. *Washington State Skill Standards*, Manufacturing Technology Advisory Group, WA State Board for Community and Technical Colleges, [www.mtag-wa.org](http://www.mtag-wa.org) (1999)
12. MatEd, The National Resource Center for Materials Technology Education, Edmonds Community College, Lynnwood, WA; <http://www.materialseducation.org/>