Analyzing Three Competency Models of Advanced Manufacturing

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Abstract

In this research paper, we present a study in which we analyzed and compared three competency models of manufacturing to assess how well the models visually communicate advanced manufacturing (AM) competencies. Advanced manufacturing covers new industrial processes that improve upon traditional methods in quality, speed, and cost. In addition, the dynamic nature of technology and innovation has made it difficult to find a unified illustration of key advanced manufacturing skills. However, three visual models of manufacturing illustrate various stakeholders' perceptions of the field and proport to depict the competencies individuals need to join the AM workforce. The three models we analyzed are: U.S. Department of Labor's *Advanced Manufacturing Competency Model,* the Society of Manufacturing Engineers' *Four Pillars of Manufacturing Knowledge,* and the National Association of Manufacturers-endorsed *Manufacturing Skills Certification System*. While the content in these models has been validated by governmental, industry, and educational stakeholders, less explored is whether these models, as visual media, are readily understandable by their intended audiences. In this paper, we will provide an in-depth analysis of these models by using the six fundamental principles of visual design by Edward Tufte (2006): comparisons, causality, multivariate analysis, integration evidence, documentation, and content. Taken together, these principles allowed us to explore the fundamental principles of design in each model and distill promising directions for further investigation into more unified depiction of the advanced manufacturing industry sector's competencies.

Introduction

A competency is the capability to apply a set of related knowledge, skills, and abilities to successfully perform functions or tasks in a defined work setting. A competency model is a collection of competencies that define successful performance in a particular work setting. Competencies are often distilled in models which are the foundation for important human resource functions such as recruitment and hiring, training and development, and performance management [1]. Competency models' content is widely used in business for defining and assessing hard and soft competencies within organizations. Some competency model creators choose to build visual depictions of competencies; however, competency model creators rarely explain how these illustrations are to be interpreted or comparative advantage their visual model provides readers. Likewise, researchers have not explored how or whether these illustrations effectively transmit their intended messages.

Among the industries that have embraced competency models is advanced manufacturing (AM). AM covers new industrial processes that improve upon traditional methods in quality, speed, and cost. High-performance computing harnesses substantial computing power to simulate real-world conditions in a virtual environment, allowing for relatively cheaper product testing [2]. However, AM's dynamic technological nature and constant innovation have made it difficult to settle upon a finite set of its disciplinary competencies. Despite this challenge, various stakeholders have distilled their views into three visual models of manufacturing. These models also visually depict the required competencies for effective AM professionals. The models are the Department of Labor's Advanced Manufacturing Competency Model; the Society of Manufacturing Engineers' Four Pillars of Manufacturing Knowledge; and the National Association of Manufacturers-endorsed Manufacturing Skills Certification System. These models were created as an integrated solution to the question of what advanced manufacturing is and what content needs to be taught in a competent manufacturing program.

In this paper, we will provide an in-depth analysis of these models by using the six fundamental principles of design by Edward Tufte [3]: comparisons, causality, multivariate analysis, integration evidence, documentation, and contents count most of all. Taken together, these principles allowed us to explore and contrast the fundamental principles of design in each model and distill promising directions for further investigation into more unified depiction of the advanced manufacturing industry sector's competencies.

Research Questions

1) How do manufacturing competency models illustrate various stakeholders' views of the field's nature and competencies it requires?
2) To what extent do these models reflect Tufte's principles of effective visual communication?

Literature Review

Stakeholders who create competency models choose a means of visual communication over textual communication. In this section, we will discuss possible reasons for and benefits of these choices define and explore visual communication,

Visual Communication

Visual communication models are derived from basic linear communication models posed by Aristotle (speaker, message, listener) and Lasswell [4] as shown in Figure 1.

Figure 1. Basic communication model [5]

Lasswell's linear model reads as "Who says what in which channel to whom with what effect?" This basic model inspired derivations that include elements that reflect additional communication elements. For example, Shannon and Weaver's model [5] factored in the role of misunderstanding, or "noise," as Figure 2 shows.

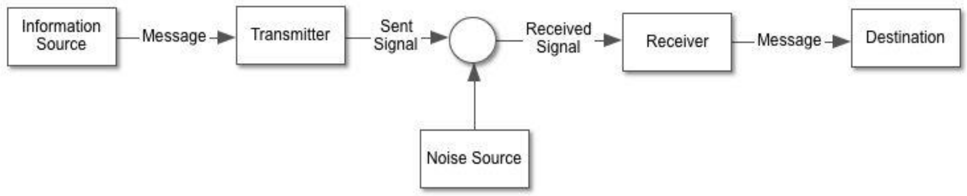

Figure 2. Communication model including misunderstanding [6]

As Figure 2 illustrates, Shannon and Weaver's model is similar to Lasswell's linear model, but incorporates confusing or misleading communication elements into the picture; this noise may confuse the signal, making it unclear for the receiver. This noise, in the words of Edward Tufte, take the form of "chart junk," which refers to chart elements that not only serve no purpose but may in fact hinder understanding. "Credibility," statistician and political scientist Tufte noted, "vanishes in clouds of chart junk" [6].

Text-based information is relatively static and words alone usually provide the most message clarity. Creators of visual information depictions make intentional choices to invite readers to interact with a visualization, instead of or in addition to text, to construct meaning. These meanings are socially constructed and mediated through education and stakeholder dialogue. For maximum impact, visually literate individuals will be able to easily and clearly analyze the information being transmitted in the visual text [7].

Visual Analysis

Visual communication has been applied widely in science, education, engineering, interactive multimedia, and medicine. Communication through visual imagery has been an effective way to communicate both abstract and concrete ideas [8]. In *Contemporary Rhetoric,* Winterowd wrote, "A conceptual framework is a schema—sometimes diagrammatic—that serves two purposes. It allows one to organize a subject, and it automatically becomes an inventive heuristic for the discovery of subject matter" [9]. Blair-Early and Zender [10] also argued that what designers need to improve interface design is a conceptual framework that can spur innovation. This conceptual framework can be first described as "parameters" essential to an interface, and then as a set of "principles" to achieve an effective interface [10].

Edward Tufte operationalized visual parameters and principles in several extremely influential books regarding the assembly and interpretation of visual models [3], [8], [11]. In these works, Tufte clearly established that we should display data visually not so much to illustrate or embellish an argument but rather because graphics are an integral step in a text's message, and can shape an argument as much as be shaped by it. Tufte posited that a wide array of graphic displays can be used to make different kinds of points or arguments more effectively, clearly, and in less space than is needed in either exclusively verbal or written communication. Tufte's approach is permeated by a fundamental commitment to the idea that visual communication is an aesthetic pleasure. In his view, effective interaction with a visual text analysis requires not only a consistent look and feel but also produce a sense of pleasure. For Tufte, visual displays are informative and effective tools because as with most useful tools, they are pleasurable and appealing to use because they are simple and versatile. Tufte called for interpreting visual displays of data to become an integral part of classroom instruction and foster graphic competence, if not sophistication, through practice [12].

Competency Models as Visual Media

Competency is defined by a set of knowledge, skills, and attitudes that enable an individual to perform the activities of a given job or occupation to or beyond expected standards. Apart from categorizing competencies, there have been few attempts to establish different levels or degrees of competence, with a few notable exceptions. Regardless, competency frameworks can benefit organizations by enabling them to describe job roles and functions, standardize performance of professionals, define expected performances, and design needs-based education and training programs [13]. Competency frameworks are visually depicted in competency models. These models can facilitate development of generic as well as context-relevant skills as desired by employers and principally focus on a clear set of desired outcomes that illustrates the requirement for valid and reliable assessment practices and tools. A competency model provides a visual structure that can be applied to a given occupation or job to serve different purposes, including accreditation, capacity building, and curriculum design and development [13].

Operationally, a competency model clearly defines each competency, measurable performance indicators, and sometimes the standards the performance will meet. Therefore, depicting competencies is a major feature of effective competency model design. Competency models are at an individual level because they describe the components of an effective professional, not the content of a professional discipline; however, since competencies are gained through learning, competency models do reflect educational content. Well-designed models clearly display effective professionals' core competencies and also provide space for secondary areas of knowledge, skill, and ability. Appropriately combining competencies into a model is similar to completing a jigsaw puzzle; the finished puzzle must depict a clear model of how competencies work together in an effective professional.

Model developers usually develop competency models through a three-step process. First, developers perform a systematic large-scale document analysis in which they gather main constructs and performance dimensions of in a professional field. Then, developers gather input from key stakeholders in the profession. These stakeholders include educators and employers to ensure that perspectives reflect both professional preparation and career engagement. These perspectives are usually gathered via interview, focus group, and/or survey [14]. Finally, competency model developers seek superior performers in a field and, through interview and observation, discern factors that make these professionals particularly effective [15].

The value of competency models is that a whole-person assessment or holistic approach can be developed to examine the competencies that an individual possesses and may still need to acquire as required by a given industry or occupation. The information can then be used workforce development professionals in various applications with the workforce. A competency model for a specific industry is one that represents types of people whom will be effective and competent in industry [16]. From a recruitment perspective, competency models visually signal areas of interest to prospective trainees and professionals. A competency model aids professional retention because it provides a fundamental guideline for workers in how they should act and what they should be doing. Competency models are also important assessment tools because they allow management could be informed on which professional characteristics are related to superior performance [17].

Method

As a basis for our analysis, we used three AM competency models: the Advanced Manufacturing Competency Model [1]; the Four Pillars of Manufacturing Knowledge [18]; and the Manufacturing Skills Certification System.

Advanced Manufacturing Competency Model

In 2006, the U.S. Department of Labor (DOL) collaborated with the Employment and Training Administration to develop the *Advanced Manufacturing Competency Model* [1]. The model was developed with industrial-organizational psychologists, along with leading industry organizations including the Society of Manufacturing Engineers (SME), Manufacturing Institute, National Council for Advanced Manufacturing, National Association of Manufacturers (NAM), and many other industry stakeholders complemented by a few education stakeholders [19]. This model defines the manufacturing skills workers need to be successful in 21st century manufacturing [20], as shown in Figure 3.

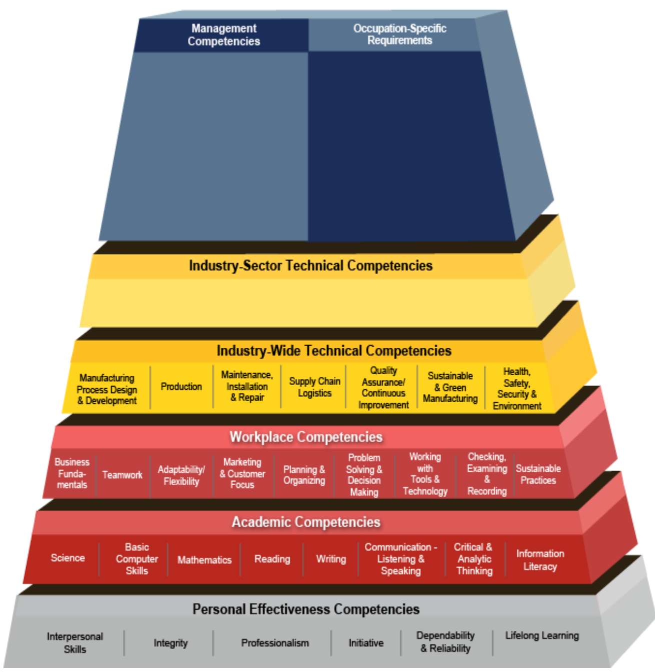

Figure 3. Advanced Manufacturing Competency Model [19]

In 2010, the DOL updated the model shown in Figure 3 by collecting feedback from leading industry organizations. The DOL built this model for manufacturers so that it could serve as a roadmap of the skills needed by workers entering and then advancing in careers across the manufacturing economy [20]. The *Advanced Manufacturing Competency Model* is a pyramid graphic with four tiers:

Tier 1: Personal Effectiveness Competencies are personal attributes essential for all life roles. Often referred to as "soft skills," personal effectiveness competencies are generally learned in the home or community and honed at school and in the workplace.

Tier 2: Academic Competencies are primarily learned in a school setting. They include cognitive functions and thinking styles. Academic competencies are likely to apply to all industries and occupations.

Tier 3: Workplace Competencies represent motives and traits, as well as interpersonal and self-management styles. They are applicable to a large number of occupations and industries.

Tier 4: Industry-Wide Competencies cover the knowledge and skills and abilities from which workers across the industry can benefit, regardless of the sector in which they operate. Many of the critical work functions on this tier deal with awareness or understanding [21].

The Four Pillars of Manufacturing Knowledge.

The Four Pillars model was completed in parallel with the comprehensive Society of Manufacturing Engineers (SME) study of manufacturing education called Curricula 2015. From 2008 to 2011 the manufacturing community met multiple times to discuss the past, current, and future state of manufacturing education [22]. The model was developed by SME through its Center for Education and derived from the ABET accreditation criteria for manufacturing engineering programs. It also builds on the topics in the SME body of knowledge for the certification of manufacturing engineers and manufacturing technologists. Figure 4 depicts the Four Pillars Model.

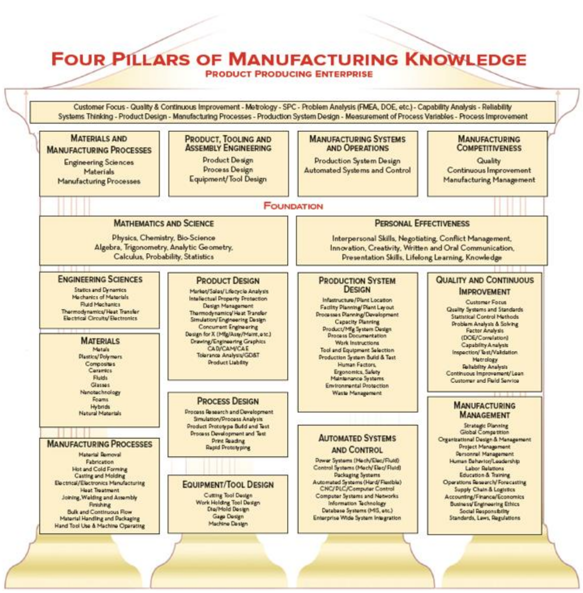

Figure 4. Four Pillars of Advanced Manufacturing [20]

The foundation shows the educational fundamentals on which the manufacturing engineering field is based, including mathematics and science, communications, and the many aspects of personal effectiveness. The four pillars are capped with the titles shown above for the four major competencies expected of manufacturing engineers and technologists. Within the four pillars, 10 major subject areas are arrayed to give more detail to the content included in baccalaureate degree programs: Engineering Sciences, Materials, Manufacturing Processes, Product Design, Process Design, Equipment/Tool Design, Production System Design, Automated Systems and Control, Quality and Continuous Improvement, and Manufacturing Management. The roof structure emphasizes that laboratory experiences, quality, continuous improvement, and problem [22].

The Skills Certification System

Figure 5 illustrates the National Association of Manufacturers (NAM)-endorsed *Manufacturing Skills Certification System* [20], based on the *Advanced Manufacturing Competency Model* shown in Figure 3 [19]. NAM built this system in 2010 for community leaders, educators, and employers in advanced manufacturing.

Figure 5. Skills Certification System [21]

As Figure 5 shows, education and work are connected through industry certifications. This system of stackable credentials is nationally portable and industry-recognized credentials. It also validates the skills and competencies identified in the *Advanced Manufacturing Competency Model* [20].

Data Analysis

Design principles consist of clear rules of thumb that have defined features. In his book *Beautiful Evidence* (2006), Edward Tufte introduced the fundamental principles of design to be used for the creation and in-depth analysis of visual information displays. According to Tufte [3] effective information designs:

1) Show comparisons, contrasts, differences.

2) Show causality, mechanism, explanation, systematic structure.

3) Show multivariate data; that is, show more than 1 or 2 variables.

4) Completely integrate words, numbers, images, diagrams.

5) Thoroughly describe the evidence. Provide a detailed title, indicate the authors and sponsors, document the data sources, show complete measurement scales, point out relevant issues.

6) Analytical presentations ultimately stand or fall depending on the quality, relevance, and integrity of their content.

Tufte argued that his design principles were universal and “not tied to any particular language, culture, style, century, gender, or technology of information display.” [3]. Furthermore, Tufte asserted that “The purpose of an evidence presentation is to assist thinking”, and that these six principles of analytical design “are derived from the principles of analytical thinking.” [3]. Considering the usefulness of Tufte’s six principles of analytical design, we will apply these principles in our analysis to provide an in-depth analysis of three models of advanced manufacturing.

Results

Tufte Principle 1: Comparisons

According to Tufte (2006), visual displays should show comparisons if they are to assist thinking. First, the *Advanced Manufacturing Competency Model* illustrates how occupational and industry competencies build on a foundation of personal effectiveness, academic, and workplace competencies in a pyramid graphic. There are three different levels in this model that are characterized by different colors: red, yellow, and purple. Each different level represents the skills, knowledge, and abilities required for successful performance in the Advanced Manufacturing industry at different stages of career [19]. This pyramid shape, common to all DOL competency models, illustrates how occupational and industry competencies build on a foundation of personal effectiveness, academic, and workplace competencies. Each tier is comprised of blocks representing the skills, knowledge, and abilities essential for successful performance in AM. At the base of the model, the competencies apply to a large number of industries. As a user moves up the model, the competencies become industry and occupation specific. However, the graphic is not intended to represent a sequence of competency attainment or suggest that certain competencies are of greater value than others [21]. They are competencies required by specific occupations in advanced manufacturing, such as managerial and engineering skills [20]. In field tests, viewers had little difficulty reading the model and readily understood how the competency tiers related to one another; in general, viewers were able to grasp the model’s content and responded positively to its organization [23], [24].

The *Four Pillars of Manufacturing Knowledge* illustrates the four knowledge areas, or "pillars": 1) Materials and manufacturing processes; 2) Product, tooling, and assembly engineering; 3) Manufacturing systems and operations; and 4) Manufacturing competitiveness [22]. Even though the model illustrates the four different pillars, the visual display of the model does explain how the pillars work together; indeed, their linear structure suggests that the pillar content is parallel and independent. The four pillars align to areas of ABET program accreditation [20], though this key point is not explicit in the model.

The *Manufacturing Skills Certification System* compares three different pathways for manufacturing workers: traditional education pathway (left column), stackable industry-based certifications (middle column) and career pathway (right column). In the diagram, traditional education pathways (left column) and stackable industry-based certifications (middle column) in manufacturing are aligned through career pathways (right column). This model illustrates which education degrees or industry certifications are needed at different stage of career.

Tufte Principle 2: Causality, Mechanism, Structure, Explanation

The effective visual displays should show causality, mechanism, explanation and systematic structure through causal analysis and logical reasoning [3]. The *Advanced Manufacturing Competency Model* has systematic structure comprised of nine tiers in a pyramid shape. This structure clearly signals the cumulative nature of the skills, knowledge, and abilities essential for successful performance in the Advanced Manufacturing industry; however, viewers may interpret the layers' decreasing size as a need to sequentially pursue skills from personal effectiveness to managerial effectiveness. The competency model does not allow for an interpretation that the competencies are intertwined and often contextual. However, DOL material that accompanies the model explains the competencies' interdependence [25], [26].

The visual display of the *Four Pillars of Manufacturing Knowledge* is represented by using the metaphor of a building. This is systematic structure that has four pillars that rest on a foundation. Below foundations, there are 10 major subject areas that give more detail to these foundations. The roof structure emphasizes that laboratory experiences, quality, continuous improvement, and problem analysis pervade the manufacturing engineering field and integrate its various facets. Below the building foundation are more detailed lists of the Four Pillars subjects. These make up the content of the programs.

The systematic structure of the *Manufacturing Skills Certification System* connects education and work through manufacturing-related industry certifications. The model explains what kind of education degrees and certifications are needed at different stages of advanced manufacturing career. Students completing programs of study earn not only an education certificate or degree, but also the relevant, transportable, industry-based certification. The curriculum in each program of study is aligned with the requirements of the industry certifications, ensuring graduates have the knowledge and skills required for jobs in today's manufacturing economy

Tufte Principle 3: Multivariate Analysis

Multivariate analysis data is composed of more than one variable. The *Advanced Manufacturing Competency Model* delineates occupational and industry competencies by two variables: competency levels, and competency skills. Three competency levels (Foundational, Core-technical, and Occupation-related) in this model are shown with different colors. Also, there are nine competency skills shown in different layers: personal effectiveness, academic competencies, workplace competencies, industry-sector competencies, industry-specific competencies, occupation-specific workplace competencies, occupation-specific knowledge competencies, occupation-specific requirement and management competencies.

The graphic representation of the *Four Pillars of Manufacturing Knowledge* encompasses three variables: four pillars, two foundations, and 10 major subject areas. The four pillars are capped with the titles shown on the top for the four major competencies expected of manufacturing engineers and technologists. Moreover, there are two foundations, which show the educational fundamentals on which the manufacturing engineering field is based, including mathematics and science, and the personal effectiveness. Another variable is ten major subject areas, which are arrayed to give more detail to the content included in baccalaureate degree programs: Engineering Sciences, Materials, Manufacturing Processes, Product Design, Process Design, Equipment/Tool Design, Production System Design, Automated Systems and Control, Quality and Continuous Improvement, and Manufacturing Management.

The *Manufacturing Skills Certification System* shows three variables: traditional education pathway, stackable industry-based certifications and career pathway. The traditional education pathway illustrates different education degrees that people can get related to advanced manufacturing. Stackable industry-based certifications show industry certifications that advanced manufacturing workers can earn. Lastly, career pathway demonstrates the different jobs you can have as you move up the career ladder.

Tufte Principle 4: Integration of Evidence

Tufte [3] suggested that effective visual displays completely integrate words, numbers, images, and diagrams. The visual displays of the *Advanced Manufacturing Competency Model* and the *Four Pillars of Manufacturing Knowledge* are only accompanied by texts. The texts in the *Advanced Manufacturing Competency Model* describe the competency levels and skills required for Advanced Manufacturing workers. In the *Four Pillars of Manufacturing Knowledge*, the texts represent the pillars, foundations, and major subject areas in Advanced Manufacturing.

The *Manufacturing Skills Certification System* has a visual display that integrated with texts and images. The texts describe different education degrees and jobs you can have as you move up the career ladder in education and career pathway respectively. The images in the *Manufacturing Skills Certification System* illustrate different industry certificates that people in advanced manufacturing can earn.

Tufte Principle 5: Documentation

Documentation in six fundamental principles of analytical design thoroughly describes the evidence, including a detailed title, author(s), sponsor(s), measurement scale(s), and citation(s)

[3]. The first model, the *Advanced Manufacturing Competency Model* does not have any documentation in its graphic representation. It does not have a detailed title, author, sponsor, measurement scale, and citation. The second model, the *Four Pillars of Manufacturing Knowledge* has a detailed title at the top. However, it does not have any other documentation. Lastly, the visual display of the NAM-endorsed *Manufacturing Skills Certification System* shows a sponsor in the bottom-right corner but does not have any other documentation.

Tufte Principle 6: Content Counts Most of All

Tufte's last principle of analytical design is "Content Counts Most of All". It asserts that all analytical presentations ultimately stand or fail depending on the quality, relevance, and integrity of their content [3]. This principle also suggests that excellent analytical graphics have a good knowledge of the content and a deep caring about the substance.

First, the *Advanced Manufacturing Competency Model* is designed for manufacturers in the field to serve as a roadmap of the skills needed by workers entering and then advancing in careers across the manufacturing economy. Moreover, the *Four Pillars of Manufacturing Knowledge* is made for advanced manufacturing employers and educators [22]. It is designed to fill in a missing link between the skills defined in the *Advanced Manufacturing Competency Model* and the *Manufacturing Skills Certification System*. Lastly, the *Manufacturing Skills Certification System* is made for both advanced manufacturing employers and educator as well. It is designed to connect education and work through manufacturing-related industry certifications. The table provides an overview of our analysis of the three AM competency models.

Table. Overview of Models in Reference to Tufte Criteria

	Advanced Manufacturing Competency Model	**Four Pillars of Manufacturing Knowledge**	**Skills Certification System**
Author	Department of Labor (DOL)	Society of Manufacturing Engineers (SME) Center for Education	National Association of Manufacturers (NAM)
Audience	• Employers	• Educators • Employers	• Employers • Educators • Workers
Principle 1. Comparisons	• Illustrates foundational core technical, and occupation-related competences	• Defines the standard for advanced manufacturing topics • Provides knowledge areas with which AM stakeholders can align.	• Compares three pathways for AM workers: traditional education, stackable industry-based certifications, career; • Depicts placement of certifications,

			degrees, and employment in career pathways.
Principle 2. Causality, Mechanism, Structure, Explanation	• Systematic structure comprised of nine competency tiers in a pyramid shape. • Structure explains the skills, knowledge, and abilities essential for successful AM industry performance.	• Systematic structure that has four pillars that rest on a foundation. • Below foundations, 10 major subject areas are detailed in relation to the pillars.	• Systematically connects education and work through manufacturing-related industry certifications.
Principle 3. Multivariate Analysis	• Delineates occupational and industry competencies by two variables: competency levels, and competency skills.	• Encompasses three variables: four pillars, two foundations, and 10 major subject areas.	• Shows three variables: traditional education pathway; stackable industry-based certifications; and career pathway
Principle 4. Integration of Evidence	• Text only • Describe the competency levels and skills required for AM workers	• Text not consistently arranged in line with pillar without explanation • Unclear whether model is to be read from top down, bottom up, or side to side	• Visually integrates text and images. • Textually describes different education degrees and jobs • Illustrate industry certificates in AM
Principle 5. Documentation	• No title or documentation in the model.	• Contains the title only at the top.	• No title; shows sponsor in the bottom-right corner.
Principle 6. Content Counts Most of All	• Maps skills needed by workers entering and then advancing in careers across the manufacturing economy.	• Bridges DOL Advanced Manufacturing Competency Model to the SME Manufacturing Skills Certification System.	• Connects education and work through manufacturing-related industry certifications.

Discussion

Our first research question was, “1) How do manufacturing competency models illustrate various stakeholders’ views of the field’s nature and competencies it requires?” Competency models supplement and extend lists of competencies through evocative illustration. Each of the models used a visual cue to send a message about its content: in the Advanced Manufacturing

Competency Model used a pyramid structure to suggest competency layers that progress from general to specific, while the Four Pillars of Manufacturing Knowledge attempted to organize knowledge within the four areas of ABET accreditation. The Manufacturing Skills Certification model illustrated relationships between and paths through certification and formal education in the AM industry. Each of three models of manufacturing is made for different purposes and audiences. The models demonstrate various stakeholders' perceptions of the field's nature and the competencies required so that individuals can bring appropriate skills and knowledge to the workforce as effective advanced manufacturing professionals. The *Advanced Manufacturing Competency Model* is built for manufacturers in the field so that it could serve as a roadmap of the skills needed by workers entering and then advancing in careers across the manufacturing industry. For this reason, the model is very practitioner focused. On the contrary, the *Four Pillars of Manufacturing Knowledge* is designed as a guideline for Bachelor of Science programs as an elaboration of the ABET accreditation criteria [20]; it can also serve as a supplement to the Advanced Manufacturing Competency Model because the Four Pillars of Manufacturing Knowledge are meant to detail the occupational skills block of the AM Competency Model [27]. Finally, the *Manufacturing Skills Certification System* helps align skills learned by earning a certification to academic programs. This model is designed specifically for industry and educational organizations looking to help their workers and learners integrate formal and informal learning opportunities.

While each of the models had a distinct visual look and feel, in discerning the answer to our second research question, "To what extent do these models reflect Tufte's principles of effective visual communication?" we encountered areas in which the models effectively conveyed the intended message. Moreover, the in-depth analysis of these models by using Tufte's fundamental principles of design, shows that their visual structure and contents are different from each other. Scientific educators and theorists have pointed to the importance of visual communication for scientific understanding; however, both established communication models and Tufte's own principles warn that visual clutter can inadvertently obscure models' messages and cloud their appeal to intended audiences. As the table indicated, all Tufte's principles were reflected to at least some extent in the models.

Conclusion

Competency models can operate as blueprints for technician education and training by specifying the advanced technological competencies that professionals need to learn and apply in their jobs. The models, being competency specific, are transparent about their outcomes and enable organizations to be focused in terms of providing appropriate instruction. Both organizations and individuals benefit, as the former are ensured that efficient practitioners are selected while the latter are clear about expectations and relevant certification. Such models also serve to strengthen the partnerships between and among education and training institutions, governmental and nongovernmental agencies, and industry. NAM pointed specifically to the competency models analyzed in this study as important means of assessing gaps between workplace needs and worker competencies [28].

Directions for Further Research

While these models may have been created by industry professionals, their development did not include feedback from intended audience [22], [26], [29]. The models are intended to communicate the vibrancy and potential of AM for prospective students and professionals as well as industry stakeholders such as investors, yet their ability to be understood by these groups has not been widely measured. The next step for us in this research is to convene groups of stakeholders outside of the models' creators and gather their perceptions of the models' meaning.

Implications for Practice

Visual literacy may be an unrecognized barrier to attaining common understanding and widespread use of competency models**.** The importance of images and visual media in contemporary culture is changing what it means to be literate in the 21st century. Yet the pervasiveness of images and visual media does not necessarily mean that individuals are able to critically view, use, and produce visual content. Individuals must develop these essential skills in order to engage capably in a visually-oriented society. Visual literacy empowers individuals to participate fully in a visual culture. Visual literacy is a set of abilities that enables an individual to effectively find, interpret, evaluate, use, and create images and visual media. In an interdisciplinary, higher education environment, a visually literate individual is able to:

- Determine the nature and extent of the visual materials needed
- Find and access needed images and visual media effectively and efficiently
- Interpret and analyze the meanings of images and visual media
- Evaluate images and their sources
- Use images and visual media effectively
- Design and create meaningful images and visual media
- Understand many of the ethical, legal, social, and economic issues surrounding the creation and use of images and visual media, and access and use visual materials ethically

Across disciplines, students engage with images and visual materials throughout the course of their education. Although students are expected to understand, use, and create images in academic work, they are not always prepared to do so. Scholarly work with images requires research, interpretation, analysis, and evaluation skills specific to visual materials. These abilities cannot be taken for granted and need to be taught, supported, and integrated into the curriculum [7].

The Association of College and Research Libraries (ACRL) *Visual Literacy Competency Standards for Higher Education* [30] established an intellectual framework and structure to facilitate the development of skills and competencies required for students to engage with images in an academic environment, and critically use and produce visual media throughout their professional lives. The Standards articulate observable learning outcomes that can be taught and assessed, supporting efforts to develop measurable improvements in student visual literacy. In addition to providing tools for educators across disciplines, the Standards offer a common language for discussing student use of visual materials in academic work and beyond.

Guthrie [31] urged all stakeholders to make competency models sustainable by striking a balance between the functional needs of industry and employers and those of educators, learners, and professionals. Frequent analysis of visual models can help to ensure that models reflect the most current industrial knowledge, skills, and abilities without generating noise that may impair readers' understanding of their content. Educators' enhanced focus on visual literacy can ensure that future professionals understand employers' expectations and the purpose of educational content.

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