Aligning Technology and Talent Development

Recommendations from the APLU- and NCMS-led Expert Educator Team

Report 1
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lift

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Introduction: Developing Education and Workforce Recommendations

Manufacturing is becoming more cutting-edge every day. Workers are expected to have advanced math skills and scientific prowess to join the workforce and continue driving innovation. Historically, much of the manufacturing workforce has been developed in two education silos: the technician, assembly, and skilled trade workers through apprenticeships and skilled training programs in vocational education and community colleges; and the engineers in university programs of study.

Now, the infusion of technology across all manufacturing sectors and at all levels of design and production requires the workforce to have higher level skills and a significant set of competencies related to new technologies, materials, and processes. Strong partnerships are needed between post-secondary education and industry. If community and technical colleges and universities are not incorporating the evolving needs of industry into their curriculum and training opportunities, their students will not be prepared for the world of innovation in advanced manufacturing.

The Aligning Technology and Talent Development initiative is an effort led by the Association of Public and Land-grant Universities (APLU) and the National Center for Manufacturing Sciences (NCMS), in partnership with the Lightweight Innovations for Tomorrow (LIFT) manufacturing institute. The initiative includes an Expert Educator Team (EET) from universities and community colleges to help identify the knowledge, skills, and abilities workers at all levels will need to deploy the technologies, materials, and processes created at LIFT. The team is helping align LIFT technology development plans with training competencies and strategies, and strengthen the connection between emerging technologies and educational programs by identifying the competencies related to using these technologies in the design or production environment, to better prepare students to enter the workforce after graduation.

Ultimately, the initiative aims to encourage more industry-driven, technology-aligned work-and-learn curricula in university and community college programs to produce graduates more capable and confident in using new manufacturing technologies and processes. Further, the effort targets the skills development needs of the incumbent workforce and engages higher education institutions in addressing these needs. The work also recognizes that STEM skills developed in K-12 are critical in developing postsecondary learning opportunities for both production and design, and in particular a re-emphasis on materials science in high school will be important.

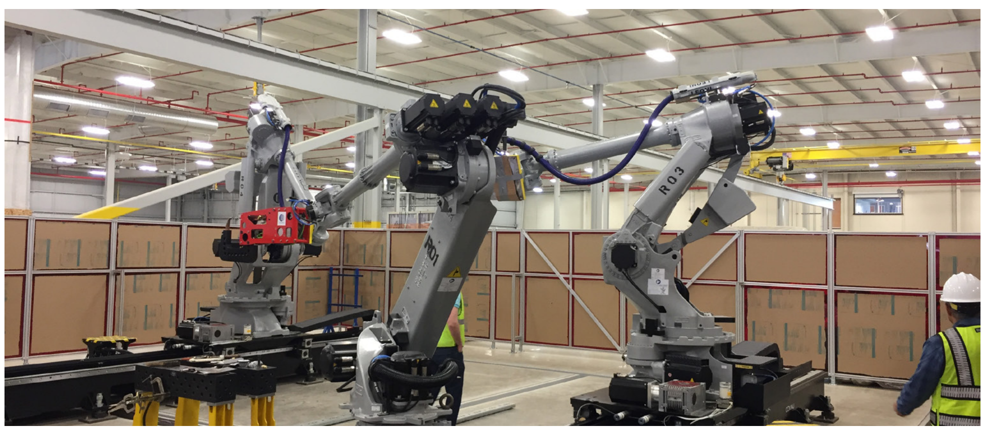
Central to implementation of the initiative is a series of quarterly meetings of the EET, at which the group works to identify workforce competencies and develop strategies aligned with LIFT technology development plans and industry goals. The first such meeting of the EET took place on February 23-24, 2017. Based on presentations and discussions at the February meeting on four LIFT technology and process focus areas, the EET has developed this report including recommendations about competencies and education and workforce strategies.

Recommendations for Leveraging LIFT Infrastructure

LIFT has already invested significantly in a wide array of technical and intellectual infrastructure that can support the delivery of the kinds of education and workforce strategies outlined in this report. Members of the Expert Educator Team were asked to develop recommendations about how LIFT could best leverage existing education and workforce infrastructure to help achieve competency development.

In this section, we present strategies for leveraging: 1) the LIFT High-Bay and Learning Lab, and 2) the many education and workforce initiatives that LIFT has already supported.

Section 1: The High-Bay and Learning Lab



Overview

The EET was excited to learn about plans for the high-bay space at the Detroit LIFT headquarters facility, including designs for a learning lab. The machines being installed in the LIFT High-Bay, combined with the adjacent learning lab facilities, represent a powerful opportunity to create work-and-learn experiences for students and teachers, and to bring together industry and education professionals to deliver world-class education and training.

Recommendations

Recommendation 1: Establish the LIFT High-Bay and Learning Lab as premier educate-the-educators facility for lightweight materials manufacturing technologies and processes.

The LIFT High-Bay promises a world of learning opportunity for teachers/professors and learners alike. Many of the existing LIFT education and workforce initiatives include a teacher training component. These programs should be reviewed for potential opportunities to deliver on-site training at LIFT. LIFT should also reach out—through APLU, NCMS, and other academic and industry partners—to colleges and universities and manufacturer's human resources and training departments to offer access to the High-Bay and Learning Lab for incorporation of these facilities into faculty development and teacher training programs. While space and time limitations will not allow for extensive portions of such programs to be delivered at LIFT headquarters, even one- or two-day learning experiences could be incorporated into educator training programs. Additional time could be spent in the LIFT Learning Lab classroom with presentations by members of LIFT technology teams.

Recommendation 2: Create short-term, iterative, technology residencies for incumbent workers and for academics.

Certifications and training conducted at LIFT could be organized into multi-step processes, with trainees visiting and training at LIFT for a couple of days and then returning to their plants (for incumbent workers) or classrooms/labs (for academics) for a number of weeks. Repeating this process for three or four cycles would allow workers and academies to develop a better understanding of the techniques learned and also appreciate the issues involved in applying learned techniques in real-life situations, the classroom, or the laboratory. For incumbent workers or academics, returning to LIFT in cycles provides an opportunity to learn more about potential causes for issues encountered in their local environment and improve further. An approach like this could be brought to scale if LIFT were to approach the National Science Foundation (NSF), potentially in partnership with Manufacturing USA or other members of the Manufacturing USA network, to spread this model across the manufacturing institutes and potentially other technology and innovation hubs.

Recommendation 3: Create a click-and-mortar field trip program to enhance student learning in lightweight materials technologies.

Students themselves can benefit from exposure to the machines and learning tools being installed in the LIFT High-Bay and Learning Lab. It will be important for LIFT to develop a strategy that makes access to such exposure available as widely as possible. The EET recommends a click-and-mortar field trip program, combining online and virtual learning modules that expose students to equipment and related instruction with the opportunity to visit the LIFT High-Bay to access the equipment in person. Such a program could be made available to college and university instructors to build into their courses, whereby students could develop a project that includes manufacturing elements tied to High-Bay equipment. A portion of the learning and project could be completed through online access to equipment walk-throughs or simulations and students could then have a culminating project experience in a trip to Detroit to visit the High-Bay and Learning Lab. Technical and engineering program instructors could partner with social sciences and arts/culture faculty at their institutions to extend the value of the field trips to include other aspects of a city experience. Of course, the ability to build in the travel component of the click-and-mortar field trip will be limited, so LIFT should consider extended virtual field trip experiences where students can experience, through real-time videocasts and virtual reality, instructors and technicians using the machines.

Section 2: Existing LIFT-Supported Education and Workforce Initiatives

Overview

The underlying principles of the LIFT work plan are:

- Be demand and data-driven
- Be transformational for sustainable results in producing workers with the right skills
- Drive from the bottom up
- Strategically focus on opportunities
- Link and leverage the assets available

As each of the projects were reviewed, the EET was asked to capture how these projects could work with existing LIFT-supported education and workforce initiatives. The goal is to develop initiatives to build educational pathways and link them via stackable credentials across the education continuum. Essential elements are captured in the recommendations below.

Recommendations

Recommendation 1: Build connections between existing LIFT-supported education and workforce initiatives and industry associations.

Later, in relation to the die-casting technology project, we note the importance of focusing on dissemination of relevant knowledge through existing professional societies like the American Foundry Society (AFS) and the North American Die Casting Association (NADCA). This kind of dissemination strategy is likely an important part of the education and workforce mix for all of LIFT's technology projects and all technology plans should be reviewed for building connections to industry organizations and professional societies. Among other approaches, LIFT should consider ways to connect industry association content to existing LIFT investments in education and workforce. Education and workforce projects LIFT has supported may also be developing content that could be disseminated by the societies and associations. Existing LIFT education and workforce initiatives could also collaborate with, for example, ASM, ASTM, SME, and ASME on design-specific projects and engage them on development and dissemination of course materials. Generally, linking the societies more closely with the education community can help advance education and workforce goals. A first step will be to task someone (perhaps a graduate student) with developing an inventory of the societies and their education and workforce assets.

Recommendation 2: Use existing education and workforce initiatives as a link between colleges/universities and industry partners to develop work-based learning.

LIFT can use existing initiatives to create a connection between industry partners/suppliers and colleges and universities to establish work-based learning and externship opportunities for students and teachers. Work-based learning provides opportunities not only for students to develop technical skills on the job, but also provides valuable experience in the work environment that helps develop communication, problem-solving, and team skills. Many of the existing LIFT education and workforce investments have demonstrated the importance of work-based learning, as a number of these projects are deploying such strategies. However, implementating these strategies may be limited by locally available expertise. LIFT should work with existing initiatives to develop train-the-trainer modules for those states/institutions offering work-based learning programs.

Recommendation 3: Leverage the network of LIFT-supported education and workforce initiatives to organize lightweight materials grand challenges.

With 40 existing education and workforce initiatives underway, LIFT has created a unique network of practitioners deploying cutting-edge strategies for developing new manufacturing competencies. Combined with the technology expertise and vision of the LIFT technology teams and the network represented by team membership, LIFT can establish a powerful lightweight materials grand challenges program. The network can allow LIFT to rapidly organize grand challenge competitions to engage the current workforce, community college and four-year undergraduate students in developing lightweight materials solutions and at the same time develop creative ideas about how best to deliver education and training for such solutions (see recommendation 2.3.1 below related to a robotic blacksmithing education and workforce challenge). These challenges reach out to the innovative and creative in people and could create out of the box ideas/processes/solutions that contribute to the technology as well as the education and workforce plans.

Recommendations for LIFT Technology Projects

The EET was provided with four projects to review at the February kick-off meeting at LIFT. The intention was to develop recommendations for two technologies and two cross cutting themes. However, one of the themes — Supply Chain — was interpreted by the EET as technology specific so the recommendations are, in fact, specific to the technology: Thin-Wall Aluminum Die Casting.

A synopsis of the four projects follows:

Integrated Computational Materials Engineering (ICME)
ICME is a cross-cutting theme for LIFT, applicable across LIFT's six technology pillars and includes the integration of materials information, captured in computational tools, with engineering product performance analysis and manufacturing process simulation. The vision is to provide robust, validated, industry-ready ICME capability to LIFT Partners to drive manufacturing innovation.

To develop recommendations related to ICME, the EET reviewed two technology project plans that are using ICME:

- **Database and Models for Corrosion-Resistant Microstructural Design** aims to develop an integrated materials property database and computational model that enables a high-fidelity probabilistic assessment of localized corrosion susceptibility and risk assessment from a specification of alloy composition, thermomechanical processing, heat treatment, and service conditions.

- **Processing for Assured Properties in Aluminum-Lithium (Al-Li) Alloys** aims to develop, implement, and validate a localized physics based viscoplastic model to predict mechanical deformation response, damage evolution mechanisms, and fatigue properties of forged Al-Li alloys.

Metamorphic Manufacturing: The Third Wave of Digital Manufacturing for Improved Competitiveness and National Security
Metamorphic Manufacturing is a manufacturing discipline poised for disruptive growth and while many of the core elements are beginning to mature, the full vision has not been realized and the technologies are not yet synthesized into a cohesive whole. Metamorphic Manufacturing is envisioned to enable the agile, rapid, and affordable production of high-quality metallic parts.

Robust Distortion Control Methods and Implementation for Construction of Lightweight Metallic Structures
This project focuses on developing solutions to prevent the distortion resulting from the production processes involved in lightweight steel structural fabrication. While many of the components of the modeling tools to identify the primary distortion drivers have been developed, this project will work through the integration and refinement of a suite of tools and recommendations for shop floor worker, designer, and production engineer use.

Thin-Wall Aluminum Die Casting Development
This project will develop process technologies (super vacuum die casting and shortened heat treatment) and integrated computational materials engineering (ICME) tools for 300 series (Al-Si-Cu-Mg based) die casting alloys to improve the mechanical properties, reduce the minimum wall thickness (up to 40%) and weight (up to 20%) of these die castings. The project will reduce the variability in quality and improve the mechanical properties of high pressure die castings. The project will also explore new design methods of lightweight castings using local mechanical properties predicted by ICME, as opposed to the current casting design using minimum properties of cast alloys.

Each of the following sections relates to these four LIFT technology projects. The EET notes have been compiled and integrated into three sections that include the following:

- Overview
- Competencies Required at Technical/Production Level (Community College)
- Competencies Required at Design/Engineering Level (4-yr University)
- Recommended Strategies for Education and Workforce Development

Recommendation

The EET recommends the technology teams review these recommendations and adopt appropriate content related to both competencies and strategies in their technology work plans.

Section 1: Integrated Computational Materials Engineering (ICME)

1.1 Overview

- Based on the initial presentations and discussions, the EET recognizes that it is just beginning to understand the power and potential of ICME, certainly among the most significant outputs of many of LIFT's technology projects. The following recommendations regarding competencies and education and workforce strategies are only a beginning in terms of what the EET expects to explore with regard to integrating ICME into technical and engineering education.

- Integrated Computational Materials Engineering (ICME) is a cross-cutting theme for LIFT, applicable across LIFT's six technology pillars (Joining and Assembly, Coatings, Novel/Agile Processing, Thermo-Mechanical Processing, Powder Processing, Melt Processing).

- To develop recommendations related to ICME, the EET reviewed two technology project plans that are using ICME: 1) *Database and Models for Corrosion-Resistant Microstructural Design*, and 2) *Processing for Assured Properties in Aluminum-Lithium Alloys*.

- Presentations on ICME in the context of these technologies were delivered by John Allison, University of Michigan Materials Science and Engineering and LIFT Technical Leader for ICME.

- Currently, the education and workforce sections of these two technology plans are limited, and little information about education and workforce strategies or plans specifically for ICME is included in either. In addition to enhancing these sections for technology-specific competencies and strategies, the EET recommends the technology teams review this section for content that can be included specifically related to ICME. Other LIFT projects employing ICME should also review this section.

1.2 Competencies

The EET recommends including the following competencies in the education and workforce sections of any technology plan making use of ICME. *Note that there may be additional competencies related to the specific technology—the competencies recommended here are related only to ICME.*

1.2.1 ICME Competencies Required at Technical/Production Level (Community College)

Technical- and production-level competencies are required for workers on the shop floor. The delivery context for content that addresses these competencies is most likely a **community college certificate or degree program**—the following competencies would be elements within courses in such certificate and degree programs.

1.2.1.1 Computer/Data Literacy

- Understand and interpret ICME tools' output
- Understand what models are and how they are used to support the production environment
- Understand different types of information needed for databases—how to supply relevant production data about alloys, processing history, quality, and characterization to further inform the development of the modeling tools
- Ability to look up materials in the database

1.2.1.2 Manufacturing Process

- Multi-process knowledge (as opposed to single skill) to optimally use different manufacturing process technologies
- Basic training in the use of the tools on the shop floor—to predict how a given processing variation will impact the product, predict if the product is within specification, etc.
- Operate and maintain equipment in electrochemical and corrosion testing
- Appropriately handle these materials

1.2.1.3 Materials Science Basics

- General appreciation for the basis of ICME models in introductory-level physics, chemistry, and materials science
- Knowledge of materials structure-properties relationship
- Understand the impact that processing conditions can have on the performance and functionality of a material
- Knowledge of the material properties that will play a significant role in any specific manufacturing process
- Knowledge of how changes in materials properties could affect product performance due to defects in manufacturing processes
- Basic training in material properties of specialized metals for lightweighting

1.2.2 ICME Competencies Required at Design/Engineering Level (4-year University)

Design- and engineering-level competencies are required for manufacturing engineers. The delivery context for content addressing these competencies is most likely a **four-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

1.2.2.1 Process Modeling, Simulation, and Analysis

- Data science competencies: understanding of big data, machine learning, deep learning; ability to conduct predictive analytics
- Process optimization and data analysis to use ICME tools for identifying optimal combination of processes
- Ability to define models needed for production processes
- Ability to use production/technical data and characterization results to further develop and use the experimentally informed and validated modeling tools needed for performance predictions
- Deep working knowledge about ICME tools and the ability to perform computationally intensive modeling, as needed
- Modeling and simulation of metal materials
- Model validation
- Design of experiments
- Advanced math
- Programming

1.2.2.2 Metallurgy/Materials Science

- Fundamentals of metal materials
- Material microstructures, how they affect property and behavior of materials
- Fundamental understanding of microstructural development and how it relates to processing, properties, and performance
- Knowledge of atomic structure of materials
- Knowledge of structure-property relationship
- Extensive understanding of materials relative to specialized metals for lightweighting

1.2.2.3 Manufacturing Process

- Knowledge of manufacturing processes
- Ability to drive product specifications

1.3 Recommended Strategies for ICME Education and Workforce Development

The EET recommends developing the following ICME education and workforce development strategies in partnership with community colleges and/or four-year universities.

1.3.1 Recommendation 1: Online ICME course development

LIFT could charge a few member universities with jointly developing an upper-level undergraduate ICME course. The course could be offered online and co-taught by experts from these member universities. The course could easily be made available for students at other universities. If centrally coordinated by LIFT, three or four such courses could be developed through member institutions, and organized into a certificate program offering.

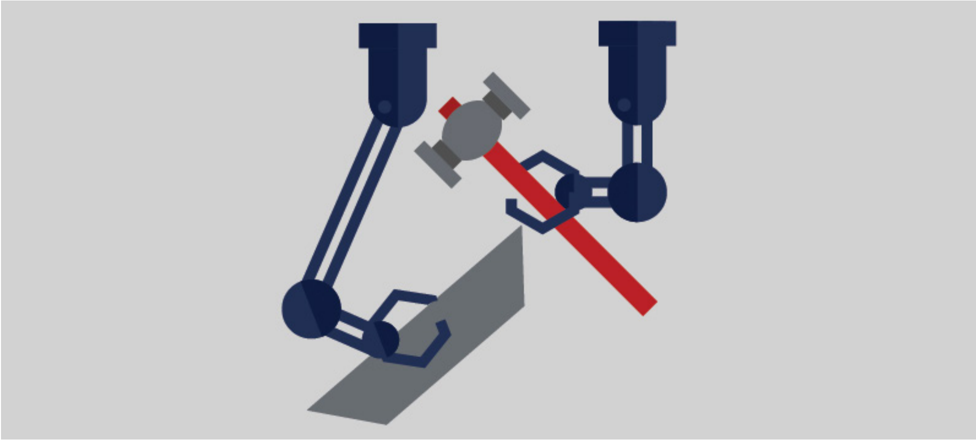
1.3.2 Recommendation 2: Multi-level, multi-disciplinary capstone design playbook

Successful ICME implementation requires technicians and engineers to work collaboratively. It is important for production-level (community college) students to work together with engineering (four-year university) students. One strategy could be to create a capstone experience design playbook for faculty and program leaders at colleges and universities, to help them design capstone projects which require groups from four-year and two-year colleges to work together. The playbook could also assist in designing capstones to require multidisciplinary (e.g. materials, chemical, mechanical engineering) and multi-trade (e.g. machinists, welders, etc.) student teams to work together. The playbook could be piloted with LIFT member institutions, with successful initial piloting leading to large-scale implementation with more institutions. LIFT could take an active role in providing incentives for institutions to develop capstones by sponsoring competitions for capstone design and for student team capstone accomplishments.

1.3.3 Recommendation 3: Faculty Development and Case Examples

For faculty to begin to integrate ICME into broader technical or engineering courses, they will need to have familiarity with ICME. A faculty training module should be developed that provides faculty with ICME basics and provides examples of ICME in practice. Exposure to manufacturing processes incorporating ICME could have a large impact for undergraduate students, and providing faculty with example modules to build into courses would make it simple to provide this exposure. ICME can be a nebulous umbrella term that is difficult to define or understand for practitioners, and even engineers and designers. Providing some concrete examples of a successful ICME approach being applied to material development or process optimization, with specific technological or economic impacts, would be very beneficial.

Section 2: Metamorphic Manufacturing



2.1 Overview

- Metamorphic Manufacturing is one of the technologies being developed under the LIFT Novel/Agile Processing pillar.

- To develop recommendations related to this technology, the EET reviewed *Metamorphic Manufacturing: The Third Wave of Digital Manufacturing for*

Improved Competitiveness and National Security—Preliminary Summary and Vision.

- A presentation on metamorphic manufacturing was delivered by Glenn Daehn, Fontana Professor, Materials Science and Engineering, The Ohio State University. Daehn is metamorphic manufacturing project leader and the Novel/Agile Processing pillar leader for LIFT.

- Currently, the metamorphic manufacturing *Preliminary Summary and Vision* document notes some education and workforce challenges and opportunities. The EET noted that while the plan does not have an extensive education and workforce section, there are throughout the document multiple mentions of knowledge, skills, and abilities required for the technology. The team members also noted that the presentation by Daehn also included a more extensive discussion of competencies than the current summary and vision document. These will be helpful when this preliminary summary is translated into a full technology work plan. The EET recommends, however, that the technology team also consider the competencies listed in this section, and additionally move beyond discussions of competencies and consider specific education and workforce strategies, such as those included here.

- Note that the vision for metamorphic manufacturing is ICME-intensive. In addition to recommendations here, all recommendations under ICME should be considered for metamorphic manufacturing.

2.2 Competencies

The EET recommends including the following competencies in the education and workforce sections of the Metamorphic Manufacturing technology plan.

2.2.1 Metamorphic Manufacturing Competencies Required at Technical/Production Level (Community College)

Technical- and production-level competencies are required for workers on the shop floor. The delivery context for content that addresses these competencies is most likely a **community college certificate or degree program**—the following competencies would be elements within courses in such certificate and degree programs.

2.2.1.1 Materials

- Basic knowledge of material properties
- Multidisciplinary skills are needed, including an understanding of metallurgical and materials engineering, thermomechanical processing, metalworking, heat-treating
- Fundamentals of alloys in aerospace applications
- Basic understanding of specialized materials for lightweighting

2.2.1.2 Technology and Computing

- Introduction to robotics and controls: basic control of robots and robotics movement, skills of operating computer controlled machines
- Experience with data acquisition systems, sensors and diagnostics, machine learning, computer programming, and industrial/manufacturing engineering
- Advanced computer literacy to use ICME tools for metamorphic manufacturing

- Introductory knowledge of digital design/manufacturing
- 3D image scanning

2.2.1.3 Manufacturing Process

- Multi-process knowledge (to understand potential issues/problems with MM)
- Knowledge of the basic forging process
- Forming process and shapes
- Knowledge of manufacturing process
- Testing equipment operation and maintenance, fatigue testing
- A basic understanding of quality assurance

2.2.2 Metamorphic Manufacturing Competencies Required at Design/ Engineering Level (4-year University)

Design- and engineering-level competencies are required for manufacturing engineers. The delivery context for content that addresses these competencies is most likely a **four-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

2.2.2.1 Materials

- Fundamental understanding of metallurgical and materials engineering, particularly physical and mechanical metallurgy, metalworking and solid mechanics, phase transformations and microstructural evolution, ICME, heat-treating, and mechanical property development is needed
- Fundamental understanding of material science, mechanical/ manufacturing engineering, as well as practical experience with thermo-mechanical processing techniques
- Sound knowledge of materials structure and properties
- Fundamentals of aerospace alloys
- Basic physics of viscoplastics
- Fatigue properties and failure
- Fracture mechanics

2.2.2.2 Technology and Computing

- Robotics/automation
- Adaptive control of thermo-mechanical processes
- Digital thread development for data extraction/machine learning and data analytics to implement metamorphic manufacturing using ICME tools and real-time process monitoring in the shop-floor
- Ability to use Materials Commons
- Computer-aided design (CAD), finite-element modeling of processing and properties, and perhaps microstructural development modeling experience
- Familiarity with data acquisition systems, sensors and diagnostics, robotics, machine learning, computer programming, and industrial/ manufacturing engineering
- Selection of the appropriate sensing technologies for a given process
- Computational background of calculation of force, stress, temperature etc., at the forging and forming process
- Knowledge of modeling and simulation of manufacturing processes
- Introductory knowledge of digital concepts and automation/sensing/ robotics relative to forming

2.2.2.3 Manufacturing Process

- Agile tools for manufacturing process hybridization
- Plastic deformation processes
- Design and manufacturing of products using sequential thermo-mechanical processes
- Cost modeling for metamorphic manufacturing based products (expert/PhD level)
- Product lifetime/functionality assessment for metamorphic manufactured products
- Knowledge of design for assembly
- Knowledge of manufacturing processes
- Fatigue testing
- A basic understanding of quality assurance and specialized materials for lightweighting and product data management

2.3 Recommended Strategies for Metamorphic Manufacturing Education and Workforce Development

The EET recommends developing the following metamorphic manufacturing education and workforce development strategies in partnership with community colleges and/or four-year universities.

2.3.1 Recommendation 1: Learn about effective practices and develop organizational capacity in prizes and challenges, and try the robotic blacksmithing challenge again.

The EET was briefed on the Robotic Blacksmithing Challenge. The model of undertaking an educational initiative concurrently with technology development holds promise, but this first effort did not get the traction the technology team was hoping for. Prize and challenge programs are a proven mechanism for prompting innovation and learning, providing an excellent platform for both informing technology development and supporting education and workforce objectives. The EET recommends that LIFT learn more about effective practices in prize and challenge programs and develop the organizational competency and capacity to use such programs in technology development and education and workforce. The EET believes it is worth re-designing after learning more about the most effective approaches to prize and challenge programs, and implementing the Robotic Blacksmithing Challenge again.

2.3.2 Recommendation 2: Extend the robotic blacksmithing challenge to a regional approach to include multi-level (technical and engineering) teams.

Again building on the success of the Robotic Blacksmithing Challenge, LIFT could extend this strategy by requiring entrants to be regional teams that include both technical and engineering level students. This type would address a frequently identified (by the EET) need of students getting this type of multi-level work experience. These experiences will help students develop not only the skills required to undertake metamorphic manufacturing at either the production or design level, but also the team and communication skills required to successfully integrate technical and engineering work.

2.3.3 Recommendation 3: Develop and disseminate an inter-disciplinary (materials and automation) course content design playbook

Metamorphic manufacturing requires development of competencies in both materials science and also robotics/automation, and ideally these competency domains should be developed in an integrated way. The EET recommends that LIFT work with an appropriate partner(s) to create and disseminate a course content design playbook to help colleges and universities develop courses that combine objectives for competency development across materials and robotics. In addition to dealing with content design, such a playbook could also include a module about agile curriculum development, which has been discussed among members of the EET as a critical need for colleges and universities. The module would include recommendations and practical ideas about how to develop curriculum in a way that is more iterative and responsive to rapid changes in technology. This module could be used in other course content design playbooks related to other technology areas.

Section 3: Distortion Control

3.1 Overview

- Distortion Control Methods is one area of technology development under the LIFT Joining and Assembly pillar.

- This project will focus on developing solutions to prevent the distortion resulting from the production processes involved in lightweight steel structural fabrication. Many of the basic components of the modeling tools to identify the primary distortion drivers have been developed, and this project will work through the integration and refinement of a suite of tools and recommendations for shop floor worker, designer, and production engineer use.

- To develop recommendations related to distortion control methods, the EET reviewed *Robust Distortion Control Methods and Implementation for Construction of Lightweight Metallic Structures*.

- A presentation on distortion control was delivered by Pingsha Dong, University of Michigan Professor of Naval Architecture and Engineering and LIFT distortion control methods technology team member.

- Currently, the distortion control technology plan provides little information. The training sessions mentioned in the document would likely be most effective at a work site involving large structures (unlikely the LIFT High-Bay and Learning Lab due to size limitations). However, a smaller demonstration piece at the LIFT facility could be effective at communicating the issues involved with distortion control. The EET recommends a review of this section by the distortion control methods technology team for content that could be included in the technology work plan.

3.2 Competencies

The EET recommends including the following competencies in the education and workforce sections of the Distortion Control Methods technology plan.

Note that the distortion control presentation generated significant discussion about the particular challenges in ship building environments. Because development of the ship building workforce has largely been insular to the industry and the companies in it, certain cultural characteristics become ingrained. Such characteristics present challenges in particular when the broader manufacturing environment is connecting with and shaping ship building. Further discussion is required to develop more complete cultural, communications, and organizational development competencies.

3.2.1 Distortion Control Competencies Required at Technical/Production Level (Community College)

Technical- and production-level competencies are required for workers on the shop floor. The delivery context for content that addresses these competencies is most likely a **community college certificate or degree program**—the following competencies would be elements within courses in such certificate and degree programs.

3.2.1.1 Basics

- Industrial/manufacturing engineering
- Rule based shop floor procedure
- Problem solving skills for continuous improvement
- Knowledge and skills to develop standardized work procedures
- Basics of geometry and tolerance
- Basic welding, joining defects and reasons
- Basic design and quality for assembly/joining
- Industry best practices for lightweight material joining

3.2.1.2 Distortion Control

- Distortion control in joining/assembly
- Knowledge of materials and properties changes in joining processes
- New/updated procedures and Welding Procedure Specifications (WPS) in material handling and processing to minimize material distortion/deformation
- Modified work processes that address distortion control and proper material handling techniques.

3.2.1.3 Process Technologies and Processing

- Process mapping/planning tools to identify, map and eliminate waste/mistakes
- Understanding of joining processes, assembly, structural engineering, data acquisition, standard operating procedures and work control documentation

3.2.1.4 Communications

- Address old practices versus new techniques; understand the importance of new processing techniques—including explanations of residual stress and heat transfer
- Remove failure of communication between levels of management and the technician to ensure new practices have traction and don't revert to old ways

3.2.2 Distortion Control Competencies Required at Design/Engineering Level (4-year University)

Design- and engineering-level competencies are required for manufacturing engineers. The delivery context for content that addresses these competencies is most likely a **four-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

3.2.2.1 Basics

- Quality control and management
- Design methodologies disseminated through company training and incorporated into formal educational programming
- Understanding of joining processes
- Standard operating procedures and work control documentation
- Cost modeling and industrial/manufacturing engineering

3.2.2.2 Product Design

- Basic design principles relative to distortion estimation and production
- Challenges to product design introduced by lightweighting

3.2.2.3 Assembly

- Modular product design and manufacturing/assembly
- Structural engineering and assembly
- Understanding of the joining mechanism and stress analysis of the process
- Geometry and tolerance; assembly variation due to manufacturing processes including fixturing and welding.
- Modeling and simulation of the joining process to estimate the stress at different joining processes

3.2.2.4 Materials Characterization and Performance

- Knowledge of materials science
- Knowledge of fracture mechanics
- Knowledge of force and stress analysis
- Understanding of transient heat transfer, material microstructure, residual stress, and multi-scale thermal expansion mechanisms
- Behavior of the lightweight material in joining: welding metallurgy and distortion control, solidification, phase transformations, microstructural development, and heat-treating
- ICME and experimentally informed and validated finite element modeling

3.3 Recommended Strategies for Distortion Control Education and Workforce Development

The EET recommends developing the following distortion control education and workforce development strategies in partnership with community colleges and/or four-year universities.

3.3.1 Recommendation 1: Develop a toolkit for design and implementation of experiential, work-and-learn curricula.

Experiential learning practices—on-site work-based learning, work-and-learn, internship and co-op experiences—for college students, engineers, and shop floor workers are critical to developing competencies in distortion control and many other technologies. Experiential learning has been recognized as a high impact practice in undergraduate programs, because students learn better when they are able to apply what they learn in the classroom in a real-world environment with hands-on experiences. Experiential learning also presents new lessons and learning opportunities to students that they cannot get in the classroom. Simply put, experiential work-and-learn practices create students that are both more knowledgeable about technology and better able to work with technology—and people—in the workplace.

There are challenges, however, to successfully designing and delivering such experiences. Some of these challenges relate to the design of meaningful education experiences. Other challenges are presented by the need for college or university departments or programs to work closely with business and industry partners in developing and delivering these experiences and the differences in time scales, cultures, and other aspects of the education and work contexts. The EET recommends that LIFT support development of a toolkit to support the design and delivery of these types of experiences. The toolkit could draw on known effective practices and the experiences—including both successes and challenges—faced by institutions and their industry partners that have already implemented effective work-and-learn experiences.

In the context of Distortion Control, development and implementation of an experiential learning toolkit should engage the principal professional society and certifying body, the American Welding Society (AWS), to create and deliver, through work-and-learn curricula, new content related to joining lightweight materials. AWS could consider including such modules in their certification programs. Also in the Distortion Control context, work-and-learn modules could be an important aspect of shipyard apprenticeship programs, given the Navy's significant 30-year shipbuilding plan.

3.3.2 Recommendation 2: Leverage Weld-Ed for module development.

Weld-Ed (www.weld-ed.org) has several regional partners, including in a couple of states within the LIFT geographic footprint. Material developed through the LIFT projects workforce and education plans can facilitate the incorporation of required content into the curriculum offered by programs such as Weld-Ed. There may be an opportunity for Weld Ed to propose/develop a project for training in lightweight materials. The module could become part of a suite of "train the trainer" modules offered on an ongoing basis.

3.3.3 Recommendation 3: Increase access to shared modeling and simulation software.

Use of modeling and simulation software would be beneficial to both companies and academia but the costs are often prohibitive. LIFT could develop a way to create more access to simulation software and offer some initial training on its use. Such an effort could provide access to tools that are otherwise out of financial reach.

Section 4: Thin-Wall Aluminum Die Casting

4.1 Overview

- Thin-wall aluminum die casting is one area of technology development under the LIFT Melt Processing pillar.

- To develop recommendations related to this technology, the EET reviewed *Thin-Wall Aluminum Die Casting Development.*

- A presentation on thin-wall aluminum die casting was delivered by Steve Uvardy, Research Director at the North American Die Casting Association (NADCA) and LIFT technology team member.

- NOTE: The intention of the EET's review of thin-wall aluminum die casting technology was originally to make recommendations about the supply chain cross-cutting theme. However, there was no emphasis on supply chain in either the technology plan or the presentation, so EET members focused their recommendations on the thin-wall aluminum die casting technology itself.

- Currently, the thin-wall aluminum die casting technology plan includes some general information about education and workforce strategies. The already-included information could be augmented by content included in this section. The EET recommends that the technology team review the competencies and strategies listed here for potential inclusion in the technology work plan.

4.2 Competencies

The EET recommends the inclusion of the following competencies in the education and workforce sections of the thin-wall aluminum die casting technology plan.

4.2.1 Thin-Wall Aluminum Die Casting Competencies Required at Technical/ Production Level (Community College)

Technical- and production-level competencies are required for workers on the shop floor. The delivery context for content that addresses these competencies is most likely a **community college certificate or degree program**—the following competencies would be elements within courses in such certificate and degree programs.

4.2.1.1 Manufacturing Competencies

- Metallurgical and materials engineering, metal casting, ICME
- Understanding the vacuum die casting machine—how it works and how to troubleshoot
- Pre-process and post-process techniques that can improve the accuracy of surface finish of a die-cast part
- General casting process, die casting process, equipment operation and maintenance
- Challenges of manufacturing of lightweight castings

4.2.1.2 Materials Competencies

- Materials properties and behavior (grain structures, mechanical properties, impact on product quality/functionality)
- Microstructural and mechanical properties
- Understanding heat transfer (solidification of thin structures), thermomechanical processes, and quality control techniques for super vacuum die-casting (SVDC) of alloys
- Lightweight materials properties and how they change during die-casting

4.2.2 Thin-Wall Aluminum Die Casting Competencies Required at Design/ Engineering Level (4-year University)

Design- and Engineering-level competencies are required for manufacturing engineers. The delivery context for content that addresses these competencies is most likely a **four-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

4.2.2.1 Design

- Design of lightweight castings (knowledge of opportunities and challenges)
- Designs of die-casting molds and die including process and equipment
- Experimentally informed and validated processes
- Microstructural and property modeling via ICME
- Thermodynamic modeling and the development of specifications
- Knowledge of die-casting is a must including CAD/DAM for design
- Knowledge of ASM and ASTM standards, etc.

4.2.2.2 Engineering

- Adaptive control
- Systems engineering
- Metallurgical and materials engineering including heat-treatment
- Transient heat transfer, solidification mechanisms, thermodynamics, and chemical kinetics
- Materials science, especially the properties of lightweight metal and how they will contribute in the die-casting process
- Fracture mechanics
- High vacuum operation

4.2.2.3 Process/Manufacture

- High-vacuum die-casting (HVDC) and process management using ICME tools
- Solidification and phase transformations,
- Metal casting experience and casting design
- Labs for students to explore how design impacts casting weight and strength

4.3 Recommended Strategies for Thin-Wall Aluminum Die Casting Education and Workforce Development

The EET recommends developing the following thin-wall aluminum die casting education and workforce development strategies in partnership with community colleges and/or four-year universities.

4.3.1 Recommendation 1: Develop a toolkit for design and implementation of experiential, work-and-learn curricula.

See recommendation 3.3.1. The same toolkit is recommended for development for thin-wall aluminum die casting.

4.3.2 Recommendation 2: Work with the North American Die Casting Association and American Foundry Society.

The members of the EET agreed it would be important for LIFT to disseminate knowledge relevant to this technology project through existing professional societies such as NADCA and AFS and their professional development or education/training efforts. LIFT can also work with trade groups to develop and disseminate metal casting and casting design content. LIFT could work with NADCA to build on their content (e.g. develop licensing agreement) to distribute to technical schools, colleges and universities for training of students and local manufacturers. LIFT could capitalize on its relationship with Learning Blade to provide an online delivery platform.

4.3.3 Recommendation 3: Provide virtual training not available at colleges and universities.

The EET recommends that LIFT provide virtual training on the advanced facilities on super vacuum die casting, which may not be available at the college and universities. In conjunction with the development of virtual training, LIFT could create a handbook of principals for high vacuum die casting processes, and using modeling and simulation software for die casting processes.

ABOUT LIFT – LIGHTWEIGHT INNOVATIONS FOR TOMORROW

LIFT is a Detroit-based, public-private partnership committed to the development and deployment of advanced lightweight metal manufacturing technologies, and implementing education and training initiatives to better prepare the workforce today and in the future. LIFT is one of the founding institutes of Manufacturing USA, and is funded in part by the Department of Defense with management through the Office of Naval Research.

ABOUT APLU

The Association of Public and Land-grant Universities (APLU) is a research, policy, and advocacy organization dedicated to strengthening and advancing the work of public universities in the U.S., Canada, and Mexico. With a membership of 237 public research universities, land-grant institutions, state university systems, and affiliated organizations, APLU's agenda is built on the three pillars of increasing degree completion and academic success, advancing scientific research, and expanding engagement. Annually, member campuses enroll 4.9 million undergraduates and 1.3 million graduate students, award 1.2 million degrees, employ 1.2 million faculty and staff, and conduct $43.9 billion in university-based research.

ABOUT NCMS

The National Center for Manufacturing Sciences, the largest cross industry collaborative Research & Development consortium in North America, is dedicated to driving innovation in commercial, defense, robotics and environmentally sustainable manufacturing. NCMS' vast experience in the formation and management of complex, multi-partner collaborative R&D programs, is backed by corporate members representing virtually every manufacturing sector.

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