Aligning Technology and Talent Development

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

Report 2
Spring 2018

Table of Contents

Introduction: Developing Education and Workforce Recommendations

Manufacturing is becoming more cutting-edge every day, and 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 trades 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 multidisciplinary, 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 has established 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 in **aligning LIFT technology development plans with training competencies and strategies**, strengthening the connection between emerging technologies and educational programs of study 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. Furthermore, the effort targets the skills development needs of the incumbent workforce and engaging higher education institutions in addressing these needs. Our work also recognizes that the STEM skills foundation developed in secondary education is critical in developing postsecondary learning opportunities for both production and design, and a re-emphasis on materials science in high school will be important in creating an education/career pathway.

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 second such meeting of the EET took place on May 4 and 5, 2017. Based on presentations and discussions at the May meeting on four LIFT technology and process focus areas, the EET has developed this report including recommendations about competencies and education/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

As mentioned in the Summer 2017 report, the state-of-the-art equipment being installed in the high-bay, combined with the adjacent learning lab facilities, represent a powerful opportunity to create work-and-learn experiences for students and teachers and incumbent workers, and to bring together industry and education professionals to deliver world-class education and training.

Recommendations

Follow-Up on Previous Recommendations

The following recommendations are follow-on notes and ideas related to the technologies discussed in Report 1 (Summer 2017) from the EET.

Recommendation 1: Host a Metamorphic Manufacturing Hackathon

LIFT has made clear the transformative potential of metamorphic manufacturing. We recommend that LIFT undertake an education and workforce initiative as soon as possible to focus on this technology. A weekend Metamorphic Manufacturing (MM) hackathon could be an interesting opportunity for LIFT and students/faculty. A hackathon could bring together multidisciplinary teams comprised of students and faculty with backgrounds that span programming, robotics, data acquisition systems, sensors and diagnostics, digital design, metallurgical and materials engineering, metalworking, manufacturing, and ICME (Integrated Computational Materials Engineering). Each university involved could partner with a local community college to promote collaboration and learning exchange among students at technical and engineering levels.

Advance preparation for the hackathon would be required. Virtual demonstrations could be given by subject matter experts in advance of the weekend hackathon. Teams could also be provided with a problem statement and a kit of parts ahead of time, allowing the teams to show up prepared and having considered the concept of MM and how it might relate to the stated problem. Expert Educator Team member Fazleena Badurdeen from University of Kentucky has already worked with Glenn Daehn from Ohio State University to produce an introductory video, "Metamorphic Manufacturing aka Robotic Blacksmithing," now posted on the Learning Hub. Development of lesson plans with case examples and supplementary videos can enhance faculty readiness to incorporate modules on MM in their existing manufacturing processes courses, further helping with hackathon readiness.

Crafting the right problem statement for the hackathon is critical—something that inspires revolutionary thought, engages students, and is at the same time simple enough that the emerging MM capabilities at LIFT can successfully demonstrate to be feasible.

The weekend hackathon could complement the planned second implementation of a Metamorphic Manufacturing design challenge. The hackathon could be scheduled in advance of the challenge and potentially be used to generate team excitement and to announce the design challenge. Alternatively, it could be scheduled in the middle of the design challenge to baseline the teams and cross pollinate ideas. A third option would be to hold the weekend hackathon at the end of the design challenge to get all the teams together and move the best practices forward.

LIFT could work with maker spaces across the U.S. to hold regional hackathons on the same weekend. Teams at the LIFT high bay could be connected via videoconference with remote teams.

Recommendation 2: Additional Ideas for Click-and-Mortar Field Trips

In its previous report (see Report 1, Summer 2017, page 5, Recommendation 3), the EET recommended a click-and-mortar feld trip program, combining online and virtual learning modules that expose students to LFT High-Bay equipment and related instruction with the opportunity to visit the LIFT High-Bay to access the equipment in person. Discussion among the Expert Educator Team at their second technology-focused meeting generated some additional ideas for developing the click-and-mortar field trips:

- LIFT could conduct live, online "ask the expert" or "ask me anything" sessions in which an equipment expert is available to answer student questions about a specific piece of equipment. An additional expert knowledgeable about specific applications of the equipment's use could also be available so students can ask both "how it works" kinds of questions and also "what can be done with it?" questions.

- Simple virtual tours of the equipment can be created using a GoPro camera mounted on a helmet, The wearer could walk through different machine components, reaching into the shot to point out specifics while narrating what the viewer is seeing.

- Live connections with classrooms could be established that allow students to see machines in action and to ask questions of operators. Live connections could follow this example at Lorain County Community College where students interact with an expert at the top of a wind turbine at Case Western Reserve University.

Recommendation 3: Convene a curriculum development summit with deans and department heads

Following up on a recommendation in its first report (see Report 1, "Recommended Strategies for Metamorphic Manufacturing Education and Workforce Development," page 15, Recommendation 2.3.3), the EET continues to recognize the need to help colleges and universities align curriculum with emerging technologies under development by LIFT technology teams. LIFT could invite the deans and department heads of mechanical and manufacturing engineering, metallurgical and materials science and engineering departments of universities in LIFT partner states. Deans and department heads could be asked how they could help to align their curriculum with LIFT projects (for example, by developing senior design capstone projects), and to provide some ideas regarding future research projects.

Recommendation 4: Review Other Report 1 Recommendations for Relevance to Technologies in Report 2

The EET recognizes that many of the recommendations made in its first report are likely appropriate to the technologies discussed in the current report. The EET recommends that the technology teams focused on thin wall ductile iron castings, powder consolidation processes, agile sheet metal fabrication, and nanoparticle reinforced aluminum review Report 1 for addional ideas. In particular, members of the EET noted the following recommendations from Report 1 as likely relevant to the technologies discussed in the current report:

- *Create short-term, iterative technology residencies for incumbent workers and for academics.* See Report 1, Recommendations for Leveraging LIFT Infrastructure, Recommendation 2 on page 5.

- *Develop a toolkit for design and implementation of experiential, work-and-learn curricula.* See Report 1, Recommended Strategies for Distortion Control Education and Workforce Development, Recommendation 1 on page 19.

- *Increase access to shared modeling and simulation software.* See Report 1, Recommended Strategies for Distortion Control Education and Workforce Development, Recommendation 3 on page 20.

New Recommendations

Recommendation 5: Begin a Webinar Series to Raise Awareness and Provide Baseline Education and Training

Webinars have become a ubiquitous form of professional development delivery. The EET recommnends that LIFT capitalize on this tool to introduce emerging and potentially transformational technologies, such as additive manufacturing of casting molds. Webinars could feature skilled presenters from technology teams or others from LIFT academic and industry partner organizations.

Recommendation 6: Develop a Certification-Focused Continuing Education Program for Incumbent Workers

The EET recognizes incumbent workers as an important audience for education and training on emerging lightweighting technology. LIFT should consider the creation of a continuing education program that focuses on certifying incumbent workers for proficiency in the technologies being developed by LIFT. A certification program could incorporate the technology residencies recommendation discussed above and in Report 1. It would be important to partner with professional societies, which may already have certification procedures in place. LIFT-related content could be incorporated into their existing offerings.

Recommendation 7: Create a LIFT Ambassadors Program

The EET discussed the importance of "giving a face" to lightweight materials, manufacturing, and the excting career opportunities in the field. The team recommends development and implementation of a LIFT Ambassadors program. Ambassadors would visit colleges and universities to present to classes or student groups like Materials Advantage Chapters, helping to make headway in changing perceptions about lightweight materials manufacturing. Ambassadors would present tangible examples of how lightweight materials are making an impact in our daily lives, and how students can make an impact in this field. Ambassadors could be recruited through LIFT academic and industry partners, and could volunteer to spend an extra day in cities or towns where they are already traveling for work. They could also be assigned to present in classrooms or to student groups in their home region.

Section 2: Existing LIFT-Supported Education and Workforce Initiatives

Overview

Included in the underlying principles of the LIFT work plan is a commitment to "link and leverage the assets available." As each of the projects were reviewed, members of the EET were 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.

Recommendation: Build on the Advanced Manufacturing Teacher Externship Experience in Kentucky to Increase Awareness

The Expert Educator Team observed that the Teacher Externship Program undertaken by the Kentucky LIFT Education & Workforce Team and the Northern Kentucky Industry Council could provide a model for LIFT teacher externships. Such externships could be focused on building awareness of lightweighting technologies and other resources available at LIFT. Teacher externships and teacher networks established through other LIFT Education & Workforce investments could be used to convey messages about the novel and innovative lightweighting technologies being developed at LIFT. As teachers develop this awareness, they can further promote awareness among the younger STEM generation. Students can learn about types of manufacturing careers and how cutting-edge they are, countering current perceptions of manufacturing careers as dirty and dangerous.

Recommendations for LIFT Technology Projects

Members of the Expert Educator Team were provided with four projects to review at the February kick-off meeting at LIFT.

A synopsis of each of the four projects follows:

Thin Wall Ductile Iron Castings
The ability to cast thin wall ductile iron (DI) castings is critical to leveraging the high stiffness and strength of these materials. Current cast iron components often have section sizes thicker, and therefore heavier, than required due to process and material limitations. By implementing improved methods and alloys, there is potential to decrease wall thicknesses by 50%, thus enabling lightweighting of transportation components by 30%-50%. This project focuses on the manufacturing process development required to bring thin-wall ductile iron (DI) castings to high volume production.

Powder Consolidation Processes
Aluminum-based, sub-micron reinforced metal matrix composites (MMCs—metals with a reinforcing material—another metal, or other material—dispsersed) fabricated using powder metallurgy technologies have superior strength-to-weight properties. This project addresses the cost of Aluminum-Silicon Carbide (Al-SiC) MMCs derived from novel mechanically-alloyed powders. Considerations include process optimization, technical cost modeling, and assessment of novel consolidation methods. These methods are believed to be lower in cost than the baseline hot isostatic pressing (HIP—a process that makes metal less porous and more dense) method, but yielding similar strength-to-weight benefits.

Agile Sheet Metal Fabrication
The aircraft industry needs a wide variety of accurately formed aluminum sheets for production. These components must meet property design and dimensional specifications. This project is developing tools that can support the fabrication of metal parts without using matching dies and still meet the specifications. Such components and low-volume production processes can speed up production time and also allow for more readily available spare components for repairs.

Nanoparticle Reinforced Aluminum
Nanocomposite materials help to improve flexibility and strength. This project is scaling up a process for producing aluminum-based nanocomposite material, and developing casting process technologies to improve performance of large, single-piece cast products. The project is also establishing Integrated Computational Materials Engineering (ICME)-based design methods for lightweighting aluminum nanocomposite castings, using ICME-predicted mechanical properties.

Each of the following sections relates to these four LIFT technology projects. Notes from members of the EET have been compiled and integrated into these sections:

- 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 Expert Educator Team recommends that the technology teams review these recommendations and adopt appropriate content related to both competencies and strategies in their technology work plans.

Section 1: Thin Wall Ductile Iron Castings

1.1 Overview

- Thin Wall Ductile Iron Casting is a technology development project within LIFT's Melt Processing pillar.
- This project focuses on the manufacturing process development required to bring thin-wall ductile iron (DI) castings to high volume production.
- To develop recommendations related to Thin Wall Ductile Iron Castings, the EET reviewed *Melt 5-A - Developing and Deploying Thin Wall Ductile Iron Castings.*
- A presentation on Thin Wall Ductile Iron Castings was delivered by Paul Sanders, Associate Professor, Materials Science and Engineering, Michigan Technological University.
- Currently, the education and workforce section of the technology plan for Thin Wall Ductile Iron Casting is limited, and little information about education and workforce strategies is included. In addition to enhancing this section for technology-specific competencies and strategies, the Expert Educator Team recommends that the technology team review this section for content that can be included.

1.2 Competencies

The Expert Educator Team recommends the inclusion of the following competencies in the education and workforce sections of the technology development plan for Thin Wall Ductile Iron Castings.

1.2.1 Thin Wall Ductile Iron Castings 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.

Basics

- Familiarity with foundry operations and iron alloy metallurgy
- Knowledge of metal casting, familiarity with casting and gating design and heat-transfer and temperature measurements
- A working knowledge of furnace operations, vacuum systems, the fabrication of casting molds and cores, casting breakout/shakeout procedures and cleaning, casting quality and yield and surface finish requirements, dimensional tolerances and machining, and heat-treatment
- Understanding of challenges associated with thin wall castings - what parameters need special attention and what makes this approach practically different from traditional casting

Metal Casting and Foundry

- Knowledge of foundry operations
- Metal casting
    - awareness of the specific challenges associated with thin wall castings
    - knowledge of mold preparation
- General understanding of iron casting processes
- Familiarity with casting and gating design
- A working knowledge of (commercially available or in-house) casting design tools, including ICME, for flow and solidification modeling
- A working knowledge of heat-transfer and importance of temperature measurements
- A working knowledge of:
    - furnace operations
    - vacuum systems
    - fabrication of casting molds and cores
    - casting breakout/shakeout procedures and cleaning
    - casting quality and yield and surface finish requirements
    - dimensional tolerances and machining,
    - heat treatment
- Knowledge of casting and foundry works
- Knowledge of machining

Materials/Metallurgy

- Knowledge of iron alloy metallurgy
- Understanding of materials characterization in terms of:
    - microstructure and properties of as-cast and/or heat-treated parts
    - sand characterization, if sand molds are used
- Computer-Aided Design (CAD) and Finite Element Analysis (FEA) experience
- Fundamentals of metal materials
- Capability to conduct:
    - Precise casting process and machine operations
    - Process and quality control
- Knowledge of stress, strain, tensile, compressive, fatigue, and hardness properties
- Basics understanding of strength of materials
- Familiartity with iron: types, structure, composition, properties, and applications

- *1.2.2 Thin Wall Ductile Iron Castings 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 **4-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

Metal Casting and Foundry

- Significant understanding of metal casting and casting and gating design, including:
  - heat transfer
  - thermophysical properties needed for modeling
- Appreciation for "older" materials specifically designed for casting (cast iron)
  - Skills to use constitutive materials models for modeling the material spring-back in DI castings, to select between single-point, double-point vs double-sided approaches for DI castings (will need to develop updated design guidelines/rules to incorporate these aspects)
- Knowledge about casting quality and yield and surface finish requirements as they relate to process development and down-stream machining
- Significant experience with (commercially available or in-house) casting design tools, including ICME, for flow, solidification, microstructure and properties
- Knowledge of:
  - General iron casting processes
  - Casting process
  - Fracture/deformation of casting parts

Materials/Metallurgy

- Material science of castings
- Significant knowledge of ferrous physical metallurgy, including:
  - Heat treatment
  - Solidification
  - Phase transformations and microstructural evolution
  - Microstructure-processing-properties-performance linkages
  - Microstructure and property characterization
- Understanding of heat treatment (proper understanding of the process conditions and mechanical properties before and after the heat treatment process; appropriate heat treatment process based on the materials and properties required)
- Experience in design of experiments
  - Benefits of using Adaptive Experiment Design techniques coupled with Bayesian optimization, as opposed to traditional Design of Experiments to explore all combinations
- Fundamentals of metal materials
- Computer-Aided Design (CAD) and Finite Element Analysis (FEA) experience
- Experience with quality control procedures and statistical analysis are also needed
- Capability to calculate stress, strain, and other mechanical properties based on the material and given conditions.
- Solid knowledge of iron and its compounds

- Knowledge of MAGMASOFT process modeling software
- Knowledge of metallography to study the microstructure
- Understanding of how material properties may change as a function of location within the cast structure due to microstructural changes that result from different transient thermal conditions

Processes

- Knowledge of project management
- Knowledge of quality control and improvement
- Understanding of the concept of thin wall casting and its implications in machining need to be covered in manufacturing processes lectures/labs
- Understanding of metal casting and casting and gating design
- Knowledge of MAGMASOFT process modeling software

1.3 Recommended Strategies for Thin Wall Ductile Iron Castings Education and Workforce Development

The EET recommends developing the following thin wall ductile iron castings education and workforce development strategies in partnership with community colleges and/or 4-year universities.

1.3.1 Recommendation 1: Develop an education and training network among hands-on casting sites and foundries at colleges and universities.

Very few schools (4-year or community college) offer any sort of hands-on casting experience (likely less than a dozen schools have this capability in the U.S., while it's very common in Europe). Perception of casting in the US is of an "old school" technology that is not cutting edge/exciting, so the industry is having a hard time attracting quality candidates to fill high tech jobs. LIFT could develop a network of these facilities that could be leveraged as satellite resources to provide exposure and training videos as well as additional sites for internships, immersive experiences, and summer camps. Such a network would allow LIFT to encourage training in physical metallurgy, solidification, and casting and foundry operations through hands-on foundry experiences for students. LIFT could also broker tours of foundries for and/or create virtual tours. Schools without foundries could send faculty or students to these select LIFT schools for a few days, weeks, or even a semester to engage in casting-related projects (potentially supported by LIFT or specific industry members).

1.3.2 Recommendation 2: Develop faculty training materials that can also be embedded into existing courses.

Development of faculty training modules can serve additional purposes. Training materials should be designed and produced so that they can then be used by faculty in their existing courses. The EET mentioned Weld-Ed as a resource in its previous report (see Report 1, Recommended Strategies for Distortion Control Education and Workforce Development, Recommendation 2 on page 19). The EET notes that Weld Ed's train-the-trainer modules could serve as a model for this. Weld-Ed's modules provide content to teaching faculty and they can choose to embed these modules in their own courses as appropriate.

1.3.3 Recommendation 3: Encourage training in physical metallurgy, solidification, and casting and foundry operations.

LIFT should encourage training in physical metallurgy, solidification, and casting and foundry operations. LIFT could achieve this by facilitating tours of foundries for faculty and students leveraging their industrial network, and/or creating virtual tours. LIFT should also introduce emerging and potentially transformational technologies, such as additive manufacturing of casting molds, through webinars and other online methods. LIFT should also leverage their relationships with trade societies by introducing students and the workforce to these organizations. These organizations may be an underutilized vehicle for delivering content.

In addition, the EET recommends exploring a partnership with the AFS Institute, formerly Cast Metals Institute, which hosts practical courses, seminars and workshops annually on all metal casting processes, materials and disciplines, both in-person online. AFS Institute could possibly leverage existing curriculum or partner to develop new courses specific to this technology.

Section 2: Powder Consolidation Processes

2.1 Overview

- Powder Consolidation Processes is one of the technologies being developed under the LIFT Powder Processing pillar.

- This project addresses the cost of Aluminum-Silicon Carbide (Al-SiC) metalmatrix composites (MMCs) derived from novel mechanically-alloyed powders.

- To develop recommendations related to this technology, the EET reviewed *Powder R1-3: Development of Cost-Effective, Advanced Mechanical Alloying, Powder Consolidation Processes for Sub-micron Reinforced Al MMC's.*

- A presentation on Powder Consolidation Processes was delivered by John Lewandowski, Director, Advanced Manufacturing and Mechanical Reliability Center, Case Western Reserve University.

- Currently, the Powder Consolidation Processes technology work plan notes some education and workforce strategies. Strategies currently listed in the plan should be augmented with strategies recommended here. The Expert Educator Team recommends that the technology team also consider the competencies listed in this section.

2.2 Competencies

The Expert Educator Team recommends the inclusion of the following competencies in the education and workforce sections of the Powder Consolidation Process technology plan.

2.2.1 Powder Consolidation 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.

Powder Handling and Consolidation

- Working knowledge about powder handling and safety
- Understanding of powder consolidation techniques, including:
  - Hot Isostatic Pressing (HIP), assembly of HIP cans
  - powder extrusion
- Understanding of vacuum and pressure systems
- Understanding of powder metallurgy and sintering/consolidation process
- Capability for powder characterization:
  - are there defects, pollutants in the powder? can it be packed well? etc.
- Knowledge of post-processing techniques (machining, forming, finishing operations, etc.) used after making the part with the powder consolidation process

Materials/Metallurgy

- Knowledge of metal working processes
  - thermomechanical processing (rolling, forging, and extrusion)
  - mechanical property and microstructure characterization
  - machining experience
- Basic understanding of what happens to materials (phase changes at each steps) and how to control the parameters to manage the consolidation process
- Understanding of effects of heat treatment
- Knowledge/hands-on training of operating the equipment for powder consolidation process
- Knowledge of quality assurance procedures
- Fundamentals of metal materials and alloys
- General knowledge of powder metallurgy

2.2.2 Powder Consolidation 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 **4-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

Powder Metallurgy

- Knowledge of powder consolidation technologies
    - Hot Isostatic Pressing (HIP)
    - Cold Isostatic Pressing (CIP)
    - Powder extrusion
    - Sintering
- Knowledge of metal working processes and steps
    - thermomechanical processing (rolling, forging, extrusion, etc.)
    - heat treatment
- Understanding of composite mixtures
- Modeling of the microstructures and properties of composite structures
- Understanding of design rules (opportunities, limitations, typical tolerances, etc.)
- Understanding of typical properties of the resulting microstructure
- Understanding of the effect of post-processing (thermal treatments, HIP, etc.) on the dimensional accuracy of parts
- Capability to design parts and components suitable for powder consolidation process
- Capability for design and optimization of the consolidation process
- Capability to design the extrusion, forging and other forming processes that could be used after powder consolidation process
- An in-depth knowledge of:
    - Fabrication of metal-matrix composites
    - Machining and forming processes
    - Powder metallurgy and processing techniques

Materials

- An understanding of the fundamentals of metal materials and alloys, including:
    - Microstructural evolution
    - Mechanical properties
- Significant materials property characterization experience
    - Full understanding of the role of processing variations on phases, distributions, amounts, etc.
    - Effects on properties and performance
- Knowledge of metallography techniques to characterize the microstructures
- Knowledge of how materials properties changes with the temperature and how this could affect the part quality

Project and Process Management

- Experience with quality control procedures
- Capability to conduct statistical analysis
- Project management skills
- Cost modeling capability
- Knowledge of quality management

2.3 Recommended Strategies for Powder Consolidation Education and Workforce Development

The EET recommends developing the following powder consolidation process education and workforce development strategies in partnership with community colleges and/or 4-year universities.

2.3.1 Recommendation 1: Develop a Learning Hub materials integration toolkit.

Recognizing the challenges of developing new courses and including them in the curriculum, the EET recommends that LIFT and college/university partners explore ways to incorporate short modules and resources into existing courses. LIFT has partnered with the Institute for Advanced Composites Manufacturing Innovation (IACMI) on the development and implementation of the Learning Hub where such modules and resources can be shared. The EET recommends the development of a Learning Hub Materials Course Integration Toolkit. Toolkits specific to technology areas, like powder consolidation processes, could be developed. The toolkit would help faculty identify best Learning Hub materials for their courses and provide lesson plans and other supporting content for course integration. The technology plan for the Powder Consolidation Processes project mentions development of a short course for technicians. Materials from this course should be made available in the Learning Hub and included in a powder consolidation processes Learning Hub toolkit.

2.3.2 Recommendation 2: Develop a problem-based learning design playbook.

The EET felt that the Powder Consolidation Processes technology project presented an ideal area for problem-based and experiential learning. Because of required competencies like materials selection, materials design, and process selection, powder consolidation could benefit tremendously from project work, lab work, and case studies that require students to perform these kinds of tasks. The EET recommends the development of a problem-based learning design playbook to help faculty incorporate development of these competencies into their courses. The playbook could recommend partnering with local industry partners to tie problem-based learning activities directly to real-world problems.

2.3.3 Recommendation 3: Develop an education and training network among powder consolidation facilities at colleges and universities.

Similar to the situation discussed in the previous section regarding hands-on casting facilities, there are few schools with powder consolidation facilities. The EET recommends connecting these facilities in a network, and leveraging that network in the same way the EET has recommended connecting and leveraging casting facilities (see Recommended Strategies for Thin Wall Ductile Iron Castings Education and Workforce Development, Recommendation 1, above).

Section 3: Agile Sheet Metal Fabrication

3.1 Overview

- Agile Sheet Metal Fabrication is one area of technology development under the LIFT Novel/Agile Processing pillar.
- This project is developing tools that can support the fabrication of metal parts without using matching dies and still meet property design and dimensional specifications.
- To develop recommendations related to Agile Sheet Metal Fabrication, the EET reviewed *Agile-R1-1 – Agile Fabrication of Sheet Metal Components with Assured Properties*.
- A presentation on Agile Sheet Metal Fabrication was delivered by Alan Taub, Chief Technology Officer for LIFT and Professor, Materials Science and Engineering, University of Michigan.
- Currently, the Agile Sheet Metal Fabrication technology plan provides little information on education and workforce development. The Expert Educator Team recommends a review of this section by the Agile Sheet Metal Fabrication technology team for content that could be included in the technology work plan.

3.2 Competencies

The Expert Educator Team recommends the inclusion of the following competencies in the education and workforce sections of the Agile Sheet Metal Fabrication technology plan.

3.2.1 Agile Sheet Metal Fabrication 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.

Basics

- Knowledge of relevant equipment
- Knowledge of mechanical properties and deformation, spring back and metallurgical properties of aluminum alloys
- Awareness of certifications and ability to conduct quality assurance

Machine Tools/Tooling

- Machining and 5-axis CNC programming skills
- Skills in robotics and programming of tool paths
- Understanding of requirements for process data acquisition during incremental forming
- Competencies in die manufacturing

Process Technologies

- Understanding of incremental forming as a process, including:
    - Operation of forming equipment
    - Clamping pressure
    - Strain rate
    - Back contract pressure (single point v shaped)
- Knowledge of heat treatment conditions, dimensional control strain measurement and measuring dimensions
- Knowledge of metal shaping and forming and how it impacts component quality

3.2.2 Agile Sheet Metal Fabrication 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 **4-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

Basics

- Solid mechanics and shaping/forming expertise
- Understanding of incremental forming
- Ability to calculate the stress, strain, and other mechanical properties based on the material and given conditions
- Experience with quality control procedures and statistical analysis
- Project management skills

Materials/Metallurgy

- Knowledge of metallography to study the microstructure
- Understanding of crystal plasticity
- Mechanical metallurgy and mechanical testing
- Materials selection
- Role of deformation and strain path on the microstructure and property evolution

Data

- Knowledge of finite element analysis (FEA)
- Measurement of local strains via nondestructive techniques
    - Strain gauges
    - Digital image correlation

- Process data collection for creation of digital thread for qualification and certification and training manuals
  - Experimentally validated modeling of mechanical behavior
- Modeling/experiments should translate to the manufacturing process via a technology transfer plan

Machine Tools/Tooling

- Programming for tool path design and transfer to production/technical level
- Knowledge of building the controller for incremental forming
- Knowledge of metal surface finishing quality

Process Technologies

- Capability for development of spring back and generation of residual stresses
- Optimization and quality control expertise
- Knowledge of design for assembly and product development
- Expertise in use of ICME
- Knowledge of geometric limitations of incremental forming

3.3 Recommended Strategies for Agile Sheet Metal Fabrication Education and Workforce Development

The EET recommends developing the following agile sheet metal fabrication education and workforce development strategies in partnership with community colleges and/or 4-year universities.

3.3.1 Recommendation 1: Use Online Videos and Webinars to Communicate the Value of Incremental Forming.

The Expert Educator Team observed that LIFT needs to communicate the value of incremental forming. LIFT should develop webinars to introduce this emerging technology to students and the incumbent workforce. A LIFT ambassador could also visit partner universities to give a seminar and engage student groups, perhaps in partnership with Materials Advantage chapters. Since incremental forming may not be possible in the laboratory in many partner universities, LIFT should leverage the capabilities available in the High Bay for work-and-learn experiences for students. There is also an opportunity for exposure to the technology through online videos. Since this technology is being pursued in automotive industrial applications already (see this video from Ford on the FT3 process from 2013), LIFT could partner with automotive manufacturers to show that this technology is practical. Videos would be helpful in motivating students and industry alike.

Section 4: Nanoparticle Reinforced Aluminum

4.1 Overview

- This project is part of the Melt Processing Pillar.
- This project is scaling up a process for producing aluminum-based nanocomposite materials, and developing casting process technologies to improve performance of large, single-piece cast products.
- To develop recommendations related to nanoparticle reinforced aluminum, the EET reviewed *In-situ Manufacturing of Nanoparticle Reinforced Aluminum Matrix Composites*.
- A presentation on Agile Sheet Metal Fabrication was delivered by by Alan Taub, Chief Technology Officer for LIFT and Professor, Materials Science and Engineering, University of Michigan.
- The full technology work plan for Nanoparticle Reinforced Aluminum currently provides little information on education and workforce development. The Expert Educator Team recommends a review of this section by the Nanoparticle Reinforced Aluminum technology team for content that could be included in the technology work plan.

4.2 Competencies

The Expert Educator Team recommends the inclusion of the following competencies in the education and workforce sections of the Nanoparticle Reinforced Aluminum technology plan.

4.2.1 Nanoparticle Reinforced Aluminum 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.

Basics

- Understanding of equipment operation
- Fundamentals of metal materials
- Knowledge of quality management
- Knowledge of casting process:
  - High pressure processes
  - Foundry operations
  - Heat treatment
  - Quality management

Process/Manufacturing

- Understanding the die cast processes
- Knowledge of formation and processing of composites, its structures, mechanical properties and applications
- Basic understanding:
  - Heat treatment
  - Metallurgy

Materials

- Understanding of various in-situ processes for nanoparticle formation
- Aluminum metallurgy and composites
- Microstructural characterization
- Understanding value of uniform distribution, size control and dispersion in nanoparticle based materials
  - Nanotechnology
  - Composites, including metal matrix composites
- Impact of materials on post processing, finishing/machining
- Knowledge of nanoparticle reinforcement strategies in aluminum metal matrix composites

Data

- Capability to conduct mechanical testing and data collection for building database

Communications

- Capability to update process documents to accommodate new materials/processes combinations

4.2.2 Nanoparticle Reinforced Aluminum 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 **4-year engineering degree program**—the following competencies would be elements within courses in such certificate and degree programs.

Design

- In-depth knowledge of:
  - Casting and alloy design
  - Component/part design
  - Design rules to allow for suitable use of the materials
  - Design for various casting processes, especially die-casting
  - Design for component and casting molds

Materials

- Understanding of composite microstructures and properties for cost effective processing
- Understanding of parameters influencing mechanical performance of reinforced MMC's
- Mastery of kinetics and nanoparticle surface energy effects to control
  - Size
  - Composition
  - Distribution
- Knowledge of physical metallurgy and metal matrix composites, including:
  - Solidification
  - Phase transformations
  - Microstructural evolution
  - Properties development
- Knowledge of nano particle reinforcement mechanisms

Process/Manufacture

- Ex-situ ultrasonic dispersion processes
- Role of processing variables on
  - squeeze and high pressure die casting
  - composite microstructures
- ICME tools for prediction of properties
- Quality control and management
- Casting processes and design
  - Heat transfer
- In-situ processing routes including scale-up
- Process modeling and optimization of percentage of reinforcement in metal matrix
- In-situ gas reaction process

4.3 Recommended Strategies for Nanoparticle Reinforced Aluminum Education and Workforce Development

The EET recommends developing the following nanoparticle reinforced aluminum education and workforce development strategies in partnership with community colleges and/or 4-year universities.

Recommendation 1: Partner with NADCA

The members of EET recommend that LIFT establish a partnership with North American Die Casting Association (NADCA) to disseminate information by a variety of means (webinars, publications, etc.) to their membership, including designers and casters. Content of webinars should focus on squeeze and die casting of nanocomposites and the mechanical properties that are generated from this work. LIFT and NADCA could develop a module on die casting that university faculty could plug into existing solidification courses. The partnership could also leverage existing university/industry research centers at partner universities to communicate the opportunities that squeeze and die casting of nanoparticle metal composites afford to a broader industrial audience.

LIFT could bring together NADCA and the target universities to develop courses or modify curriculum to meet the required skill gaps. Further, LIFT can team with NADCA to offer certification program with schools in die casting using aluminum metal matrix composites.

The EET also recognizes that access to NADCA local process experts will benefit faculty in including the appropriate level of content / projects/ labs into coursework. It would also be helpful in connecting educators to local companies utilizing these casting processes for class tours.

Recommendation 2: Develop Evidence-Based Education for Nanoparticle Reinforced Aluminum.

The EET suggests adopting Evidence-Based Education for this technology. As an example, the model used by the Institute for Evidence-Based Education at Southern Methodist University could be evaluated. This approach :

1. Creates and scientifically evaluates well-designed, curricular materials, strategies, and tools to assist teachers in delivering highly effective instruction
2. Designs valid, reliable ongoing assessment tools to help teachers determine which students are succeeding and which need additional support, and
3. Examines the role technology can play supporting teachers through ongoing, job-embedded staff development, coaching, and professional communities of learning.

The EET realizes that this is a comprehensive undertaking, but if LIFT is to develop any educational materials to increase the dissemination of knowledge about the new technologies, some of these activities will have to be undertaken to facilitate the process.

Recommendation 3: Provide on-line and in-person awareness and training.

Most manufacturing engineering curricula do not teach die casting in detail, not to mention the availability of hands-on laboratory experiences. An introductory course in nanotechnology might be needed.

The EET recommends increasing awareness through LIFT by hosting weekly/ monthly webinars. Webinars would be for raising awareness only, not for in-depth knowledge sharing. Currently, the EET observes that such awareness outside the LIFT community of members and partners is sparse. Many faculty, even those teaching manufacturing processes courses, do not seem to be aware of the work that is being done at LIFT. Webinars can be an easy way to increase awareness – even if they do not attend the webinar, the announcements themselves can increase awareness of the work being done and they will know where to look for, when the need arises.

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.

Association of Public & Land-Grant Universities

1307 NEW YORK AVENUE, N.W., SUITE 400
WASHINGTON, D.C. 20005-4722
(202) 478-6040
WWW.APLU.ORG

FACEBOOK.COM/APLUNEWS @APLU_NEWS YOUTUBE.COM/APLUNEWS