NSF Workshop on Frontiers of Additive Manufacturing Research and Education

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Anticipating the Broad Implications of Additive Manufacturing on Workforce Development and Education

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Why Teach Additive Manufacturing?

Why Teach Additive Manufacturing?

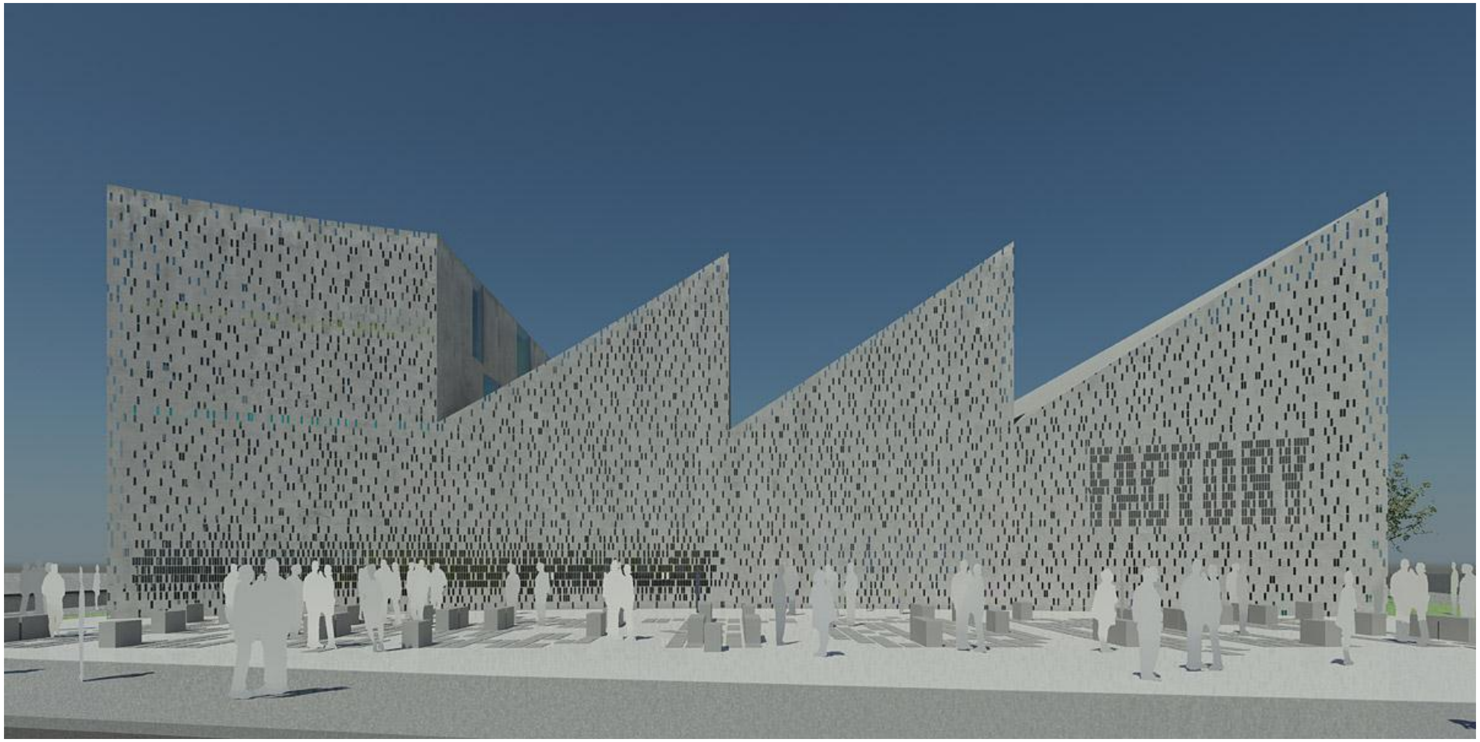
Empower people
to build what they **dream**.

Developing Workforce and Education Framework

- Who should we teach / train?
- What should we teach / train?
- How should we teach / train?
- Challenges and opportunities?

To begin to answer these, we must understand how AM fundamentally changes the manufacturing and education environments.

Reimagining Manufacturing



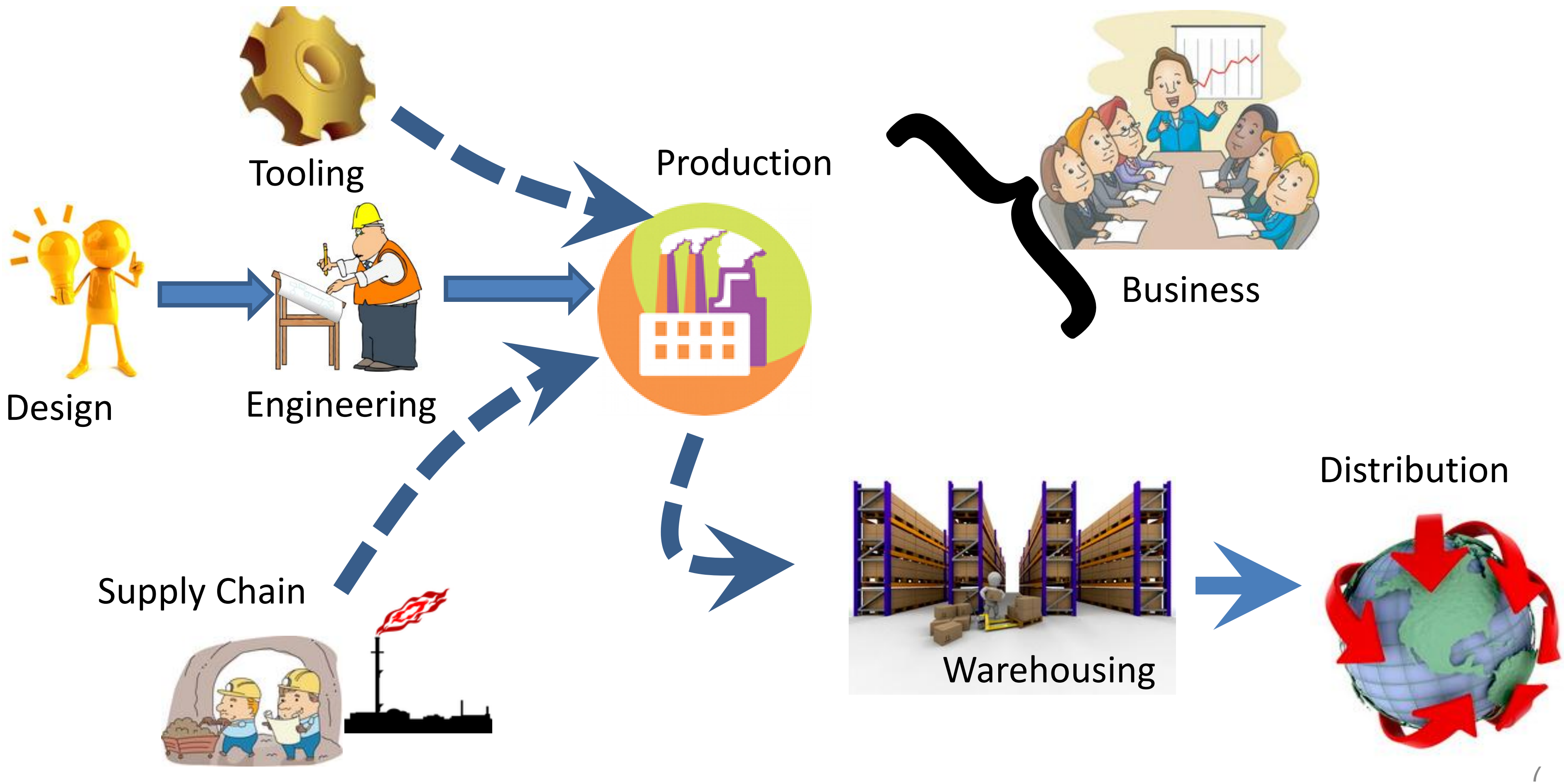
Rethinking the Problem

Barriers to broader adoption of AM:

- Cost
- Confidence

- Solutions to these challenges are different for AM than for traditional processes.

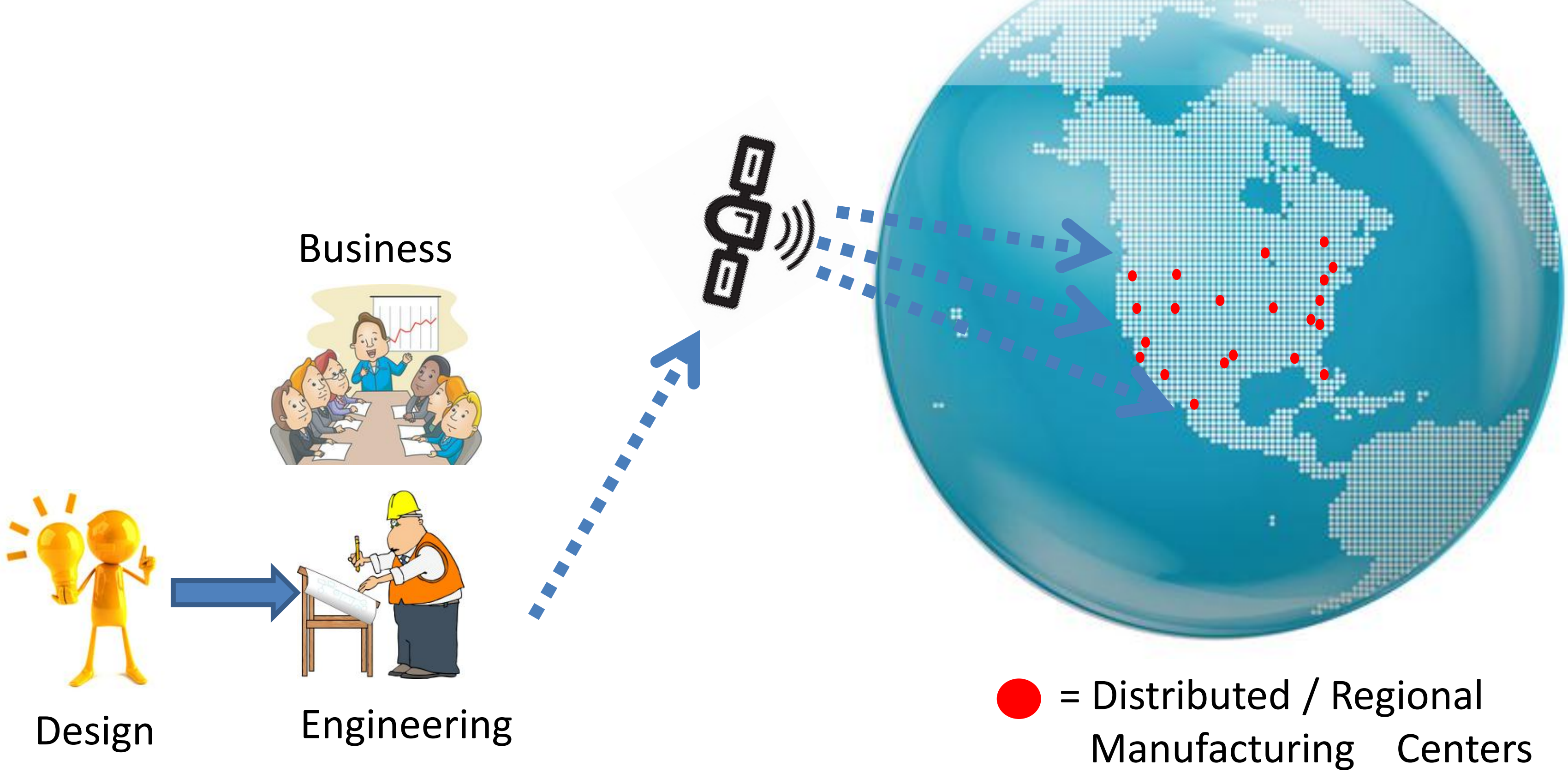
Traditional Model for Manufacturing



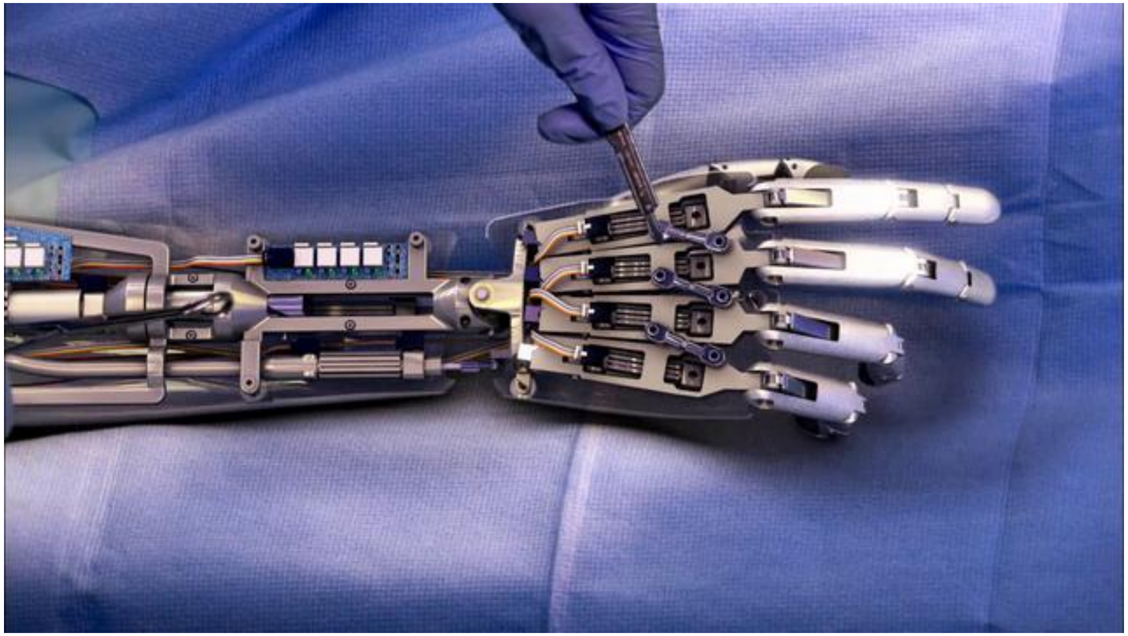
Disruptive Technology will Change the Downstream Model

- Warehousing
- Distribution
- Tooling
- Stock Losses / Risk
- Carrying costs
- EOQ / amortization schedules

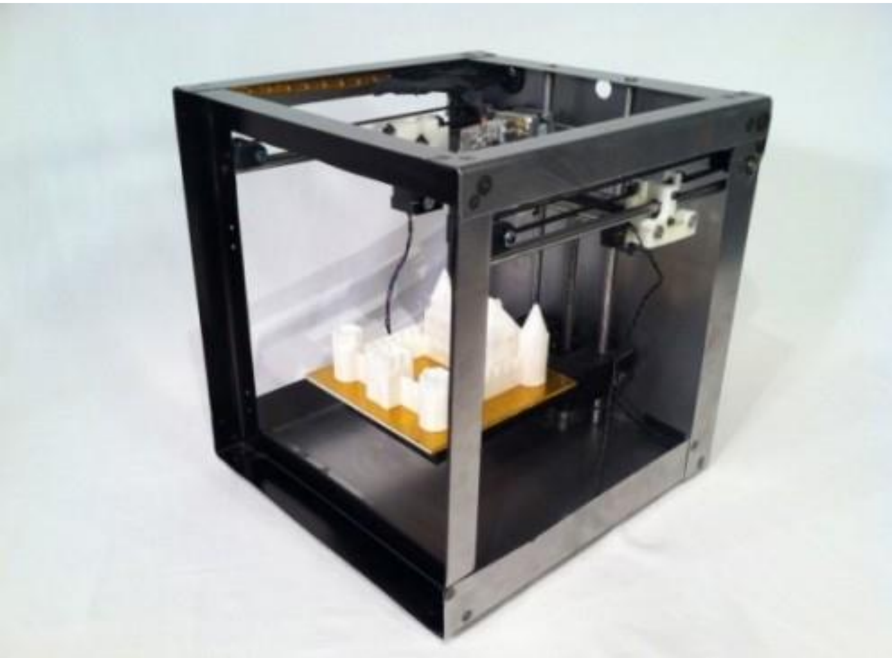
New Models for Manufacturing: "Traditional" Manufacturers



Additive Manufacturing Changes Who Can be a "Manufacturer"



Affordable



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XBOX 360
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Accessible

≈

Which is the “Consumer” Product?

	Milling Machine	Boutique Coffee Maker
Ability to directly control process parameters (speeds, temperatures)	Limited only by machine capabilities	Pre-set configurations
Ability to directly customize cycle (time/temperature / toolpath)	Unlimited	Pre-set configurations
Raw Materials and tools	Best available based on price and properties	Limited selection, OEM packaged, expensive
Flexibility to innovate	High	Low

Which is the “Consumer” Product?

	<$2000 “Hobby” 3D Printer	>$50,000 “Commercial” 3D Printer
Ability to directly control process parameters (speeds, temperatures)	Limited only by machine capabilities	Pre-set configurations
Ability to directly customize cycle (time/temperature / toolpath)	Unlimited	Pre-set configurations
Raw Materials and tools	Best available based on price and properties.	Limited selection, OEM packaged, expensive
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Innovation from the Grass Roots

- Materials
- Software
- Toolpaths
- Equipment

Component printed with Laywoo-D3 composite wood filament

Familiar Trajectory

digital

IBM

IBM System 370
1972
1 MIPS

Intel 286
1982
2.66 MIPS

Accelerated

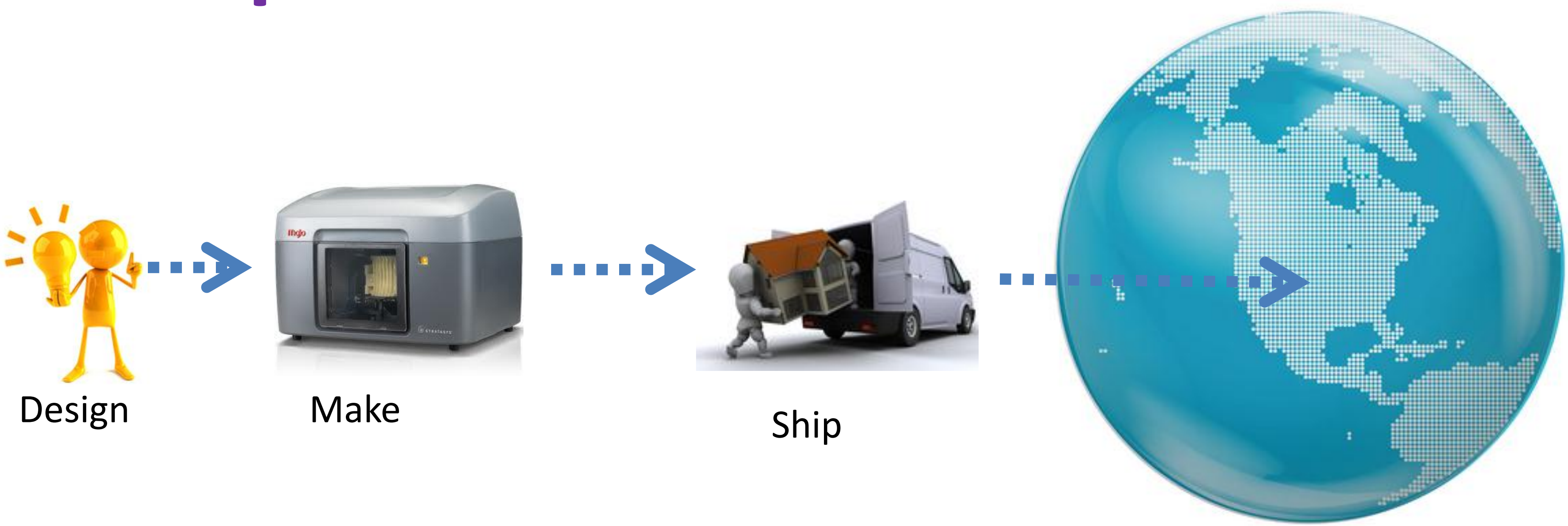
2011

2012

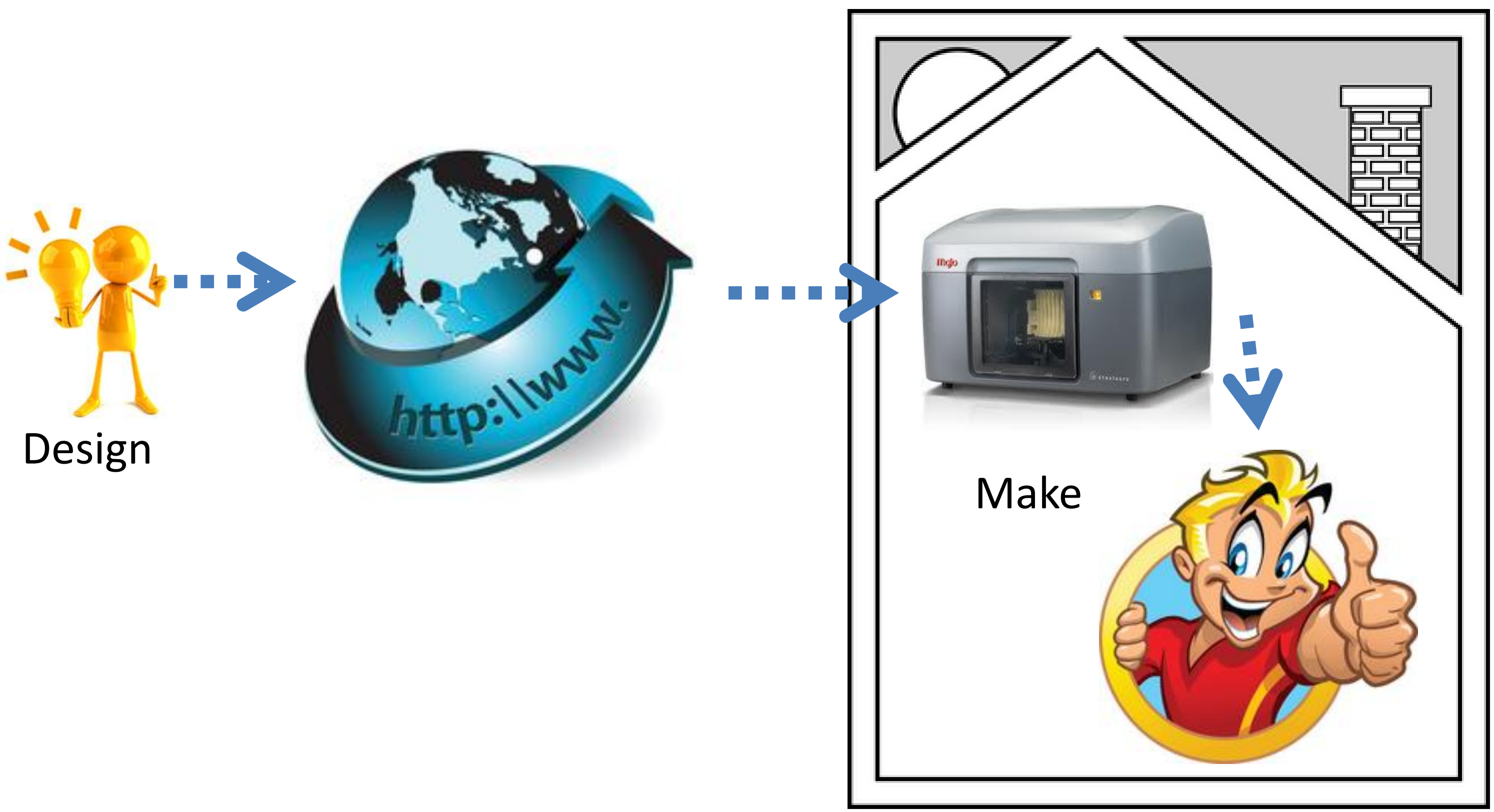
Reduces the barriers to entry

- Low cost for prototyping
- Production parts do not require capital investment
- Innovations are not limited to technology firms

The Individual Manufacturing Entrepreneur



Designs as Apps



Who do we Teach / Train?

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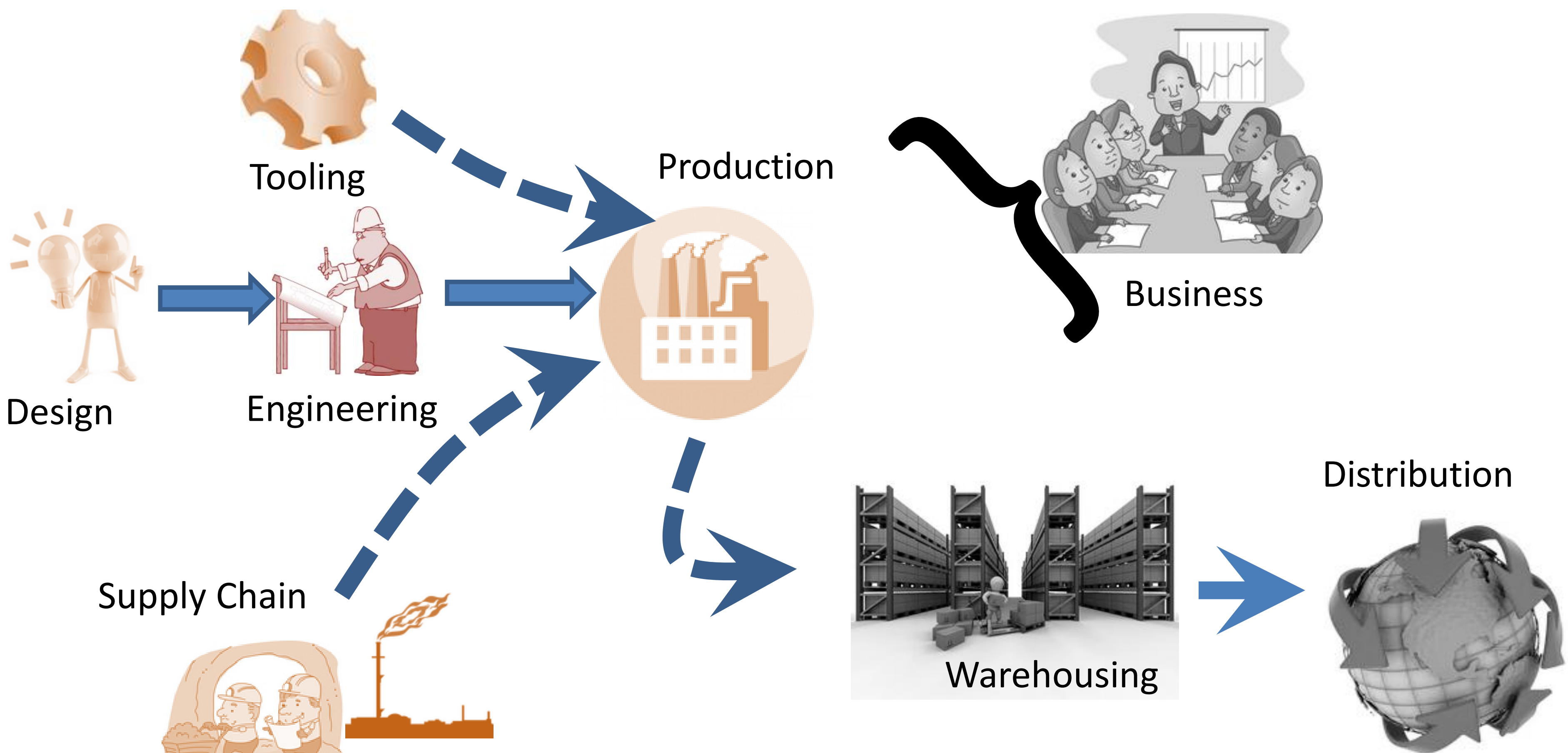
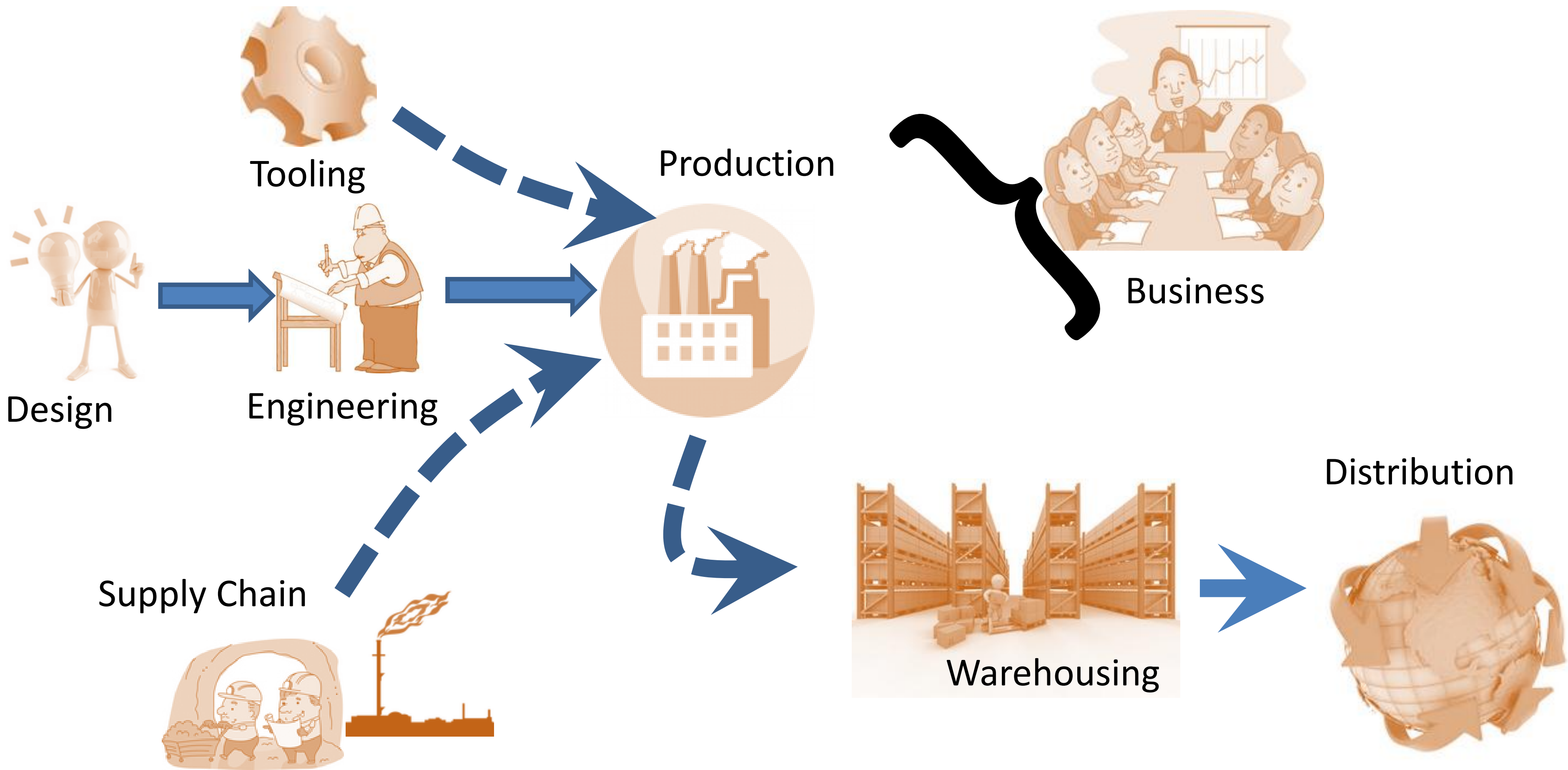
"Workforce"– Traditional View



Traditional View of "Workforce"

- Non-Degree
- Labor
- Technichians / Technologists

"Workforce" Impacted by AM



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A Broader Look at "Workforce"

Traditional view in Manufacturing

- Broadened Age Range:
  - K-Gray
  - **Non-Degree** through Ph.D.
- Broad disciplines:
  - **Labor**
  - STEM
  - Creative
  - Entrepreneurial
  - Business Enterprise

Identified Focus Areas for Workforce and Education

- General Awareness
  - Public, K-12
- **Workforce (non-degree through graduate curricula)**
  - **AM Foundational Understanding**
  - **AM Technology / Process and Materials**
  - **AM Inputs**
  - **Design for AM**
  - **Quality Assurance for AM**
  - **AM Enterprise (Business and Economics)**
- Advanced AM Research / Education

Identified Target Groups for Education and Workforce Development

- Public
  - General public
    - The curious
    - The contentious
- Government
  - Poltical leaders
  - Economic development agencies
- Individual entrepreneurs / Makers
- K-12
  - Students
  - Faculty
  - Administrators
  - Parents
- Technical / non-Degree
  - Students
  - Faculty
  - Administrators
- 2- and 4-year Degree Programs
  - Students
  - Faculty
  - Administrators
- Graduate Degrees / R&D
  - Students
  - Faculty
- Industry by Role
  - Floor Labor
    - Operators
    - Technicians
  - Engineering and Design
    - Manufacturing Engineers
    - Designers / Design Engineers
  - Business and Administration
    - Management
    - Finance
    - Inventory Management
    - Transportation and Logistics
    - Legal
- Industry by Segment
  - Manufacturers
    - Component suppliers
    - OEM manufacturers / integrators
  - Material Suppliers

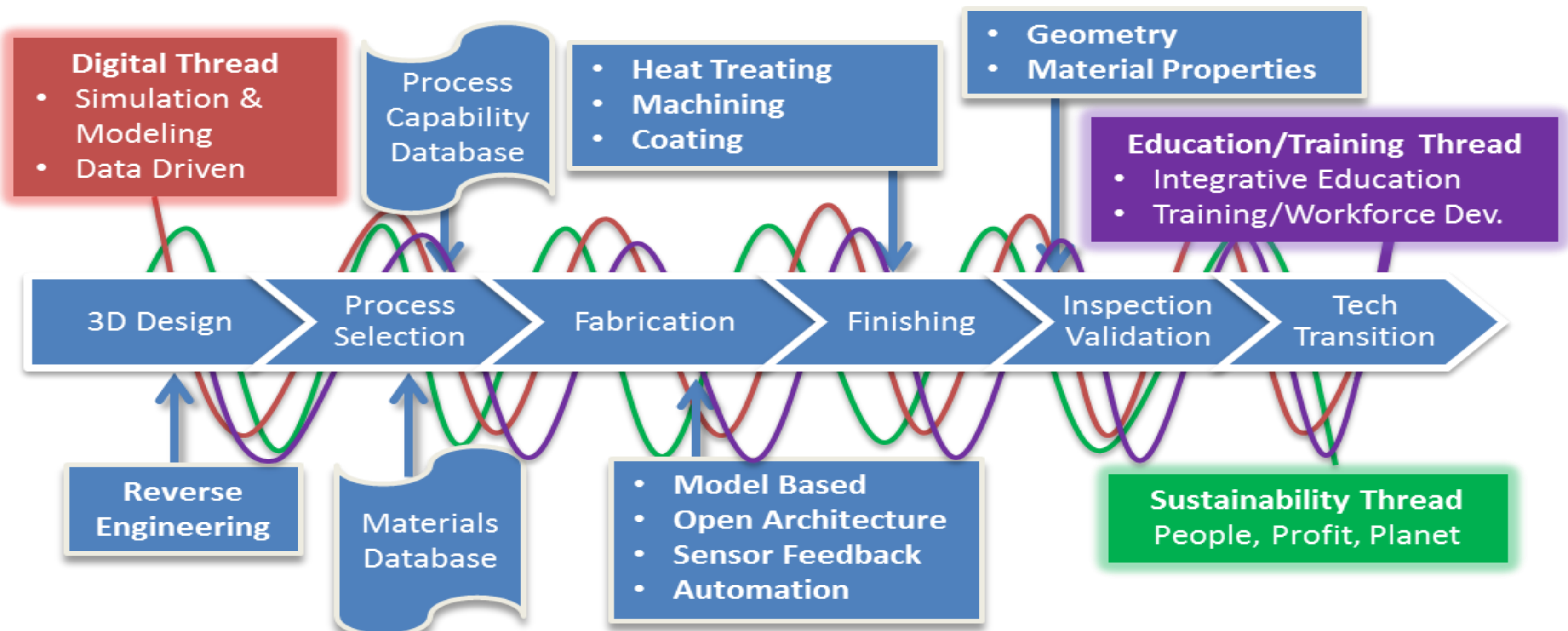
Evolution of Job Market

Job market and technology adoption are closely related

- Demand for technicians / operators will depend on viability of AM in manufacturing enterprise
- Viability of AM will depend on proper training of designers, engineers, executives, finance, logistics, etc.

What do we Teach / Train?

Additive Manufacturing as an Integrated System



What do we Teach?

- **What we can teach effectively today:**
  - AM Processes
  - Multidisciplinary teaming
- **Topics that depend on further development:**
  - AM design communication
  - Costing and enterprise-level design decisions
  - AM design methodologies

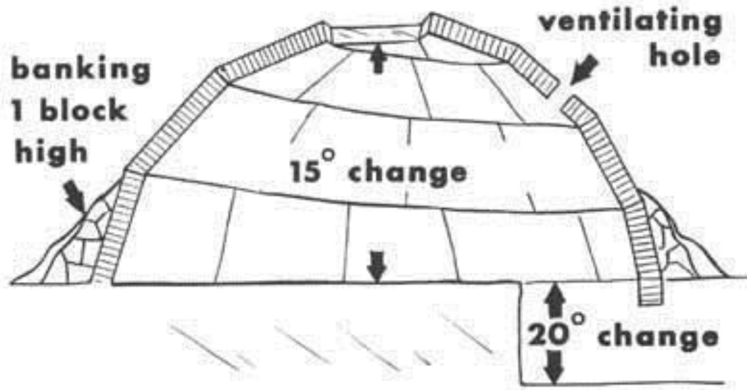
AM Processes

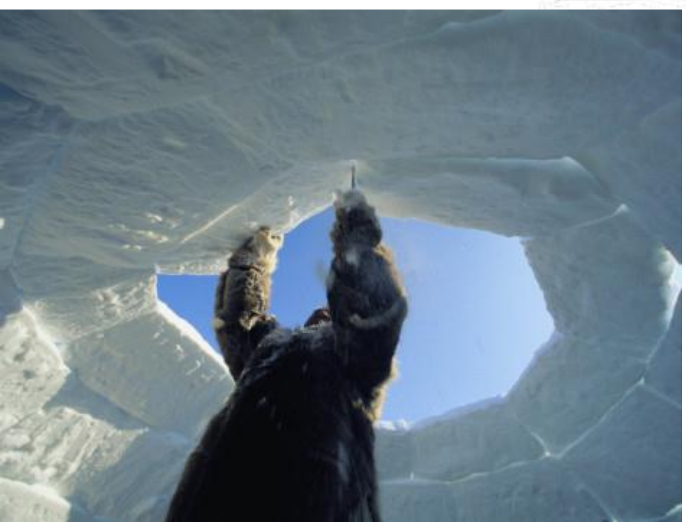
- Essential for manufacturing professionals to understand in the context of traditional manufacturing processes.
  - Capabilities and limitations
  - Differentiation between various AM processes (not “Catch All”)

A Unique Bottleneck in Human History

- Papyrus
- Phonetic alphabet
- Gutenberg press
- 3-View orthographic projections
- Tolerances
- Geometric Dimensioning and Tolerancing
- Digital models (still evolving)
- **Design and communication tools for AM**

Everything I Needed to Know about AM Design Communication … I learned from an Igloo





Igloo Language

- Layer-wise construction technique
- Requires specialized language to describe
  - English language: “snow”
  - Inuit language: 15 lexemes with 1000+ inflected forms to describe “snow” (several of the lexemes are important for the igloos)
- Building the structure properly requires the right combination of types of snow.
  - Inuits use precise language to unambiguously describe
  - Other languages fumble around with modifiers: “new-fallen snow, hard-packed crust, sticky snow” etc.

Chain of Design Communication

- Design
  - Specifications
  - acceptable tolerances around nominal
- Manufacturing
  - produce parts and assemblies within tolerance
- Validation
  - Based on unambiguous specifications
  - Based on measuring outcomes against specifications

In a Different Context

“Color” as a Design Parameter

- Traditional design parameters are discrete / quantized, seldom continuously varying.
- Complex contours are already a challenge for traditional design communication tools.
- Characteristics that vary in through-body gradients are much more difficult to specify / satisfy / verify.

“Color” of Parts – 3D Gradients

Some things we can currently control:

- Material composition
- Micro/Macro structure
  - Microstructure
  - Gross anisotropy (build orientation)
  - Local anisotropy (tool path)
  - E-materials (multi-material deposition patterns)

How do we Specify / Verify?

- What is the language to communicate the “color” parameters of our parts?
- What is our ability to measure and verify
  - gradated properties
  - Internal geometric features

Are our designs hampered by communication?

We can make designs that we can’t effectively communicate.

How, therefore, do we teach it?

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Teaching Additive Manufacturing

- Teaching and learning depend on effective communication
  - Present concepts
  - Manipulate concepts

DFAM (Design for Additive)

- Design for Manufacturing and Assembly (DFMA) rules have evolved to be generally applied across traditional manufacturing processes.

- AM disrupts
  key assumptions.

How do we Teach / Train?

Evolving Curriculum in Parallel with Technology

- Technology is available at all levels of education
- Not yet well understood or broadly adopted in industry
- Technology and pricing will likely change dramatically over a short time period

AM Curriculum Development and Credentials

- AM processes developing at a faster pace than curricular programs can keep up.
- NAMII will support shared, current resources
- Aligning degree, course, certificate, and certification program content with nationally recognized consensus materials will **foster broader credential recognition**.

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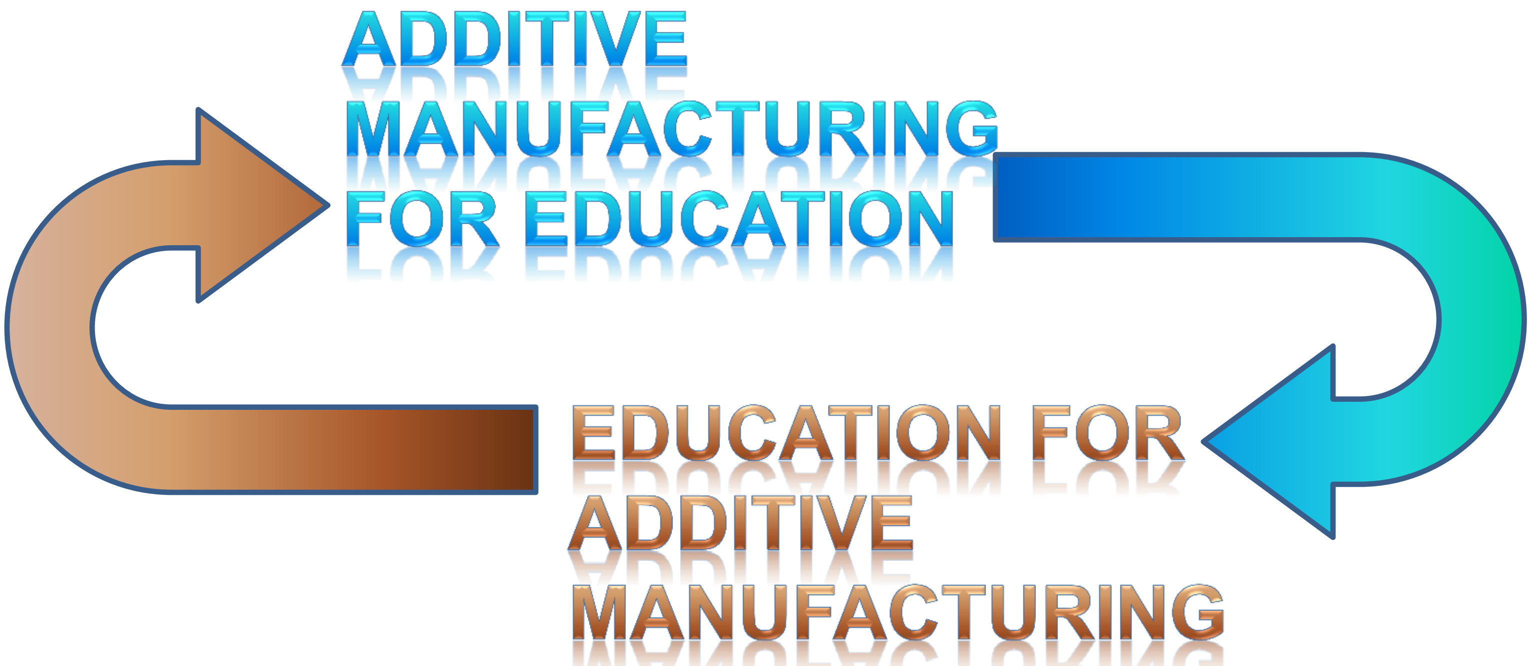

Challenge and Opportunity

- 83% of US manufacturers report an overall shortage of qualified employees
- 59-milion K-12 Students
  - Attracting just 1% more to pursue careers in STEM / manufacturing would have tremendous impacts
- Total number of 3D printers sold worldwide to-date numbers only in tens of thousands.

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Leveling the Playing Field

- Anyone with an idea can be a manufacturer
- Same technology will be used across broad ranges demographics

Experiential Learning

- Empower students at all levels to create the tools that allow them to learn
- Open-ended, multi-disciplinary challenges
- AM as a classroom resource to be used whenever applicable

Growing the Pie

- Opens up opportunities for the largest untapped populations
  - Hands-on experimentation at all levels of education attracts kids who are kinesthetic learners
  - Low barriers to innovation and entrepreneurship
  - Cost of technology is approachable

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Inspiring Ingenuity

2013 First Robotics National Championship

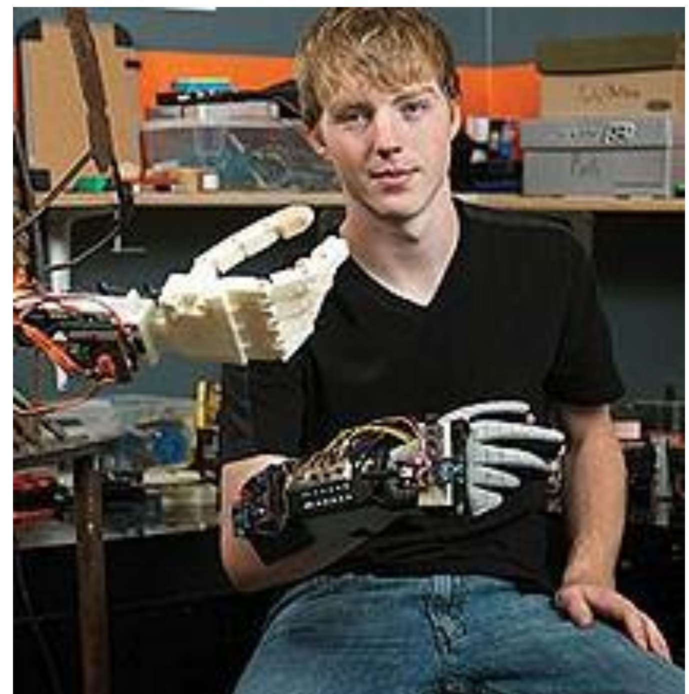
- Students make what they can't buy
- On-site parts hospital

- Philosophy of empowerment and self-reliance
- Demonstration of "cloud sourcing" - more than 2300 parts in 2 weeks

Empower Everyone

The best solution to any problem lies outside of your organization.

Easton LaChappelle, 15 year old inventor of a 3D printed prosthetic arm that can be controlled by nerve and brain impulses for less than $250.



Conclusion

- The opportunities offered by AM are revolutionary.
- Dissemination of the technology to the many potential users will democratize manufacturing and spur innovation.
- Many of the biggest challenges are tied to the rapid rate of evolution.
- The ability to educate our students, workers, and enterprises about this technology is best served by a thriving, dynamic, and connected community of technology experts, manufacturers, and educators.

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