Board 99: Assessing the Results of an Additive Manufacturing Course at Three Large Universities on Undergraduates and High School Students

Dr. Patricia Ann Maloney, Texas Tech University

Dr. Patricia Maloney is an assistant professor in the Department of Sociology, Anthropology, and Social Work at Texas Tech University. Dr. Maloney has 10 years of experience as a sociologist of education and holds a master's in education from the University of Pennsylvania, focusing on individual- and program-level assessment. She also holds a master's in sociology, a master's in philosophy, and a doctorate in sociology from Yale University. Previous to academia, she was a middle school science teacher in a predominantly minority, low-income school, thus giving her special insight on how to adopt these topics for K-12 students. Dr. Maloney's current research focuses on immigrant students, their teachers, and standardized tests in K-12 schools.

Dr. Weilong Cong, Texas Tech University

Dr. Weilong (Ben) Cong is an Assistant Professor in Department of Industrial Engineering at Texas Tech University (TTU). Dr. Cong received a Ph.D. in Industrial and Manufacturing Systems Engineering at Kansas State University in 2013. After graduation, Dr. Cong worked as a Post-Doctoral Fellow and a Research Assistant Professor at Kansas State University for one year. Dr. Cong's current research activities mainly include ultrasonic vibration-assisted additive manufacturing process of high performance metallic materials and laser additive manufacturing of ceramic and composite materials. Dr. Cong has taught two undergraduate manufacturing classes and two graduate advanced manufacturing classes at TTU.

Dr. Meng Zhang, Kansas State University

Dr. Meng (Peter) Zhang is specifically interested in preprocessing (pelleting and size reduction) for advanced biofuel manufacturing, additive manufacturing, and engineering education innovation. He teaches manufacturing processes and renewable energy. Dr. Zhang is actively involving undergraduate engineering students in his research projects with a tradition in providing research opportunities for undergraduates, especially for those who from the underrepresented group.

Prof. Bingbing Li, California State University, Northridge

Dr. Bingbing Li is an Assistant Professor in the Department of Manufacturing Systems Engineering & Management at California State University Northridge. He teaches undergraduate and graduate courses in Manufacturing Systems Engineering. His research includes additive manufacturing (laser additive manufacturing, 3D bioprinting, FDM & SLA for plastics), sustainable design and manufacturing, and sustainability analysis of nanotechnologies.

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WIP: Implementation and Assessment of Project

Background:

Additive manufacturing (AM) is prevalent in academic, industrial, and layperson use for the design and creation of objects via joining materials together in a layer upon layer fashion [1-5]. While it is not a new technology, its recent increase in popularity in likely due to the shift from rapid prototyping to processes that now use ceramics, metal, composites, and polymers to manufacture a wide variety of durable and fully functional products in varying quantities [6-8]. It is a multi-billion dollar industry, with sales predicted to reach $10.8 billion by 2020 [9]. AM is one of the key areas of focus for the White House in supporting United States manufacturing [10] and is in use by a majority of large manufacturers, including Lockheed Martin, GE, Boeing, Google, and Rolls Royce [11-13].

However, after we completed a survey of the curriculum at approximately 60 other colleges of engineering, we learned that almost no universities have a permanent undergraduate course dedicated to it. Thus, using NSF IUSE support 1712311 from the Exploration and Design Tier of the Engaged Student Learning Track, this project has created and implemented such a course at three large universities: Texas Tech University (TTU) (a Carnegie high research productivity and Hispanic Serving Institution), Kansas State University (KSU) (a Carnegie high research productivity and land grant university) and California State University, Northridge (CSUN) (the largest of all the California State campuses and highly ranked in serving underprivileged students). Our research team includes engineering professors and a sociologist trained in assessment and K-12 outreach to determine the effects of the course on the undergraduate and high school students. We are currently in year two of the three years of NSF support. CSUN is a HSI (Hispanic Serving Institution), AANAPISI (Asian American Native American Pacific Islander Serving Institution), and non-PhD-granting institution. TTU is a university with high research activity (RU/H) and is an HSI, while KSU is both an Established Program to Stimulate Competitive Research (EPSCoR) and RU/H institution.

The Course

The course focuses on the fundamentals of the three families of prevailing AM processes: extrusion-based, powder-based, and liquid-based, as well as learning about practical solutions to additive manufacturing of common engineering materials including polymers, metals and alloys, ceramics, and composites. It has a lecture plus lab format, in that students learn the fundamentals in a classroom, but then apply and broaden their knowledge in lab projects and independent studies. By the end of the semester, our goal is that students will:

- Understand the core concepts and evolving technologies of different additive manufacturing processes.
- Create the design of an object suitable for additive manufacturing processes and use commercial software to digitize the free-form geometry.
- Describe and evaluate the capabilities, procedures, typical applications, the relative advantages and limitations of additive manufacturing processes.

- Define and apply the criterion to select the appropriate additive manufacturing process for any given applications.
- Have hands-on experiences on the additive manufacturing of fabricating and testing parts as well as provide solutions to the current problems in additive manufacturing.

Additionally, as outreach, we host field trips from local high schools (and one middle school) during which the undergraduates give presentations about discrete AM skills, then lead the high school students through a lab project focused on those skills. This creates a pipeline of knowledge about AM for younger students as well as an opportunity for undergraduates to develop leadership and speaking skills while solidifying their knowledge. We are also in the process of uploading videos and lab projects to an online Google Classroom so that those with access to 3D printers in other areas can learn online for free. We are also self-publishing an accompanying textbook and lab manual. More information will be here about both the class and the textbook as we continue on with the semester and refine our data.

Assessment Strategy:

Beyond the course itself, one of the innovations of our project is the assessment strategy. For both undergraduates and high school students, we have been able to collect content area knowledge both before and after completing the class, as well as information about their attitudes towards engineering and self-efficacy beliefs. This has been particularly illuminating in regards to subgroups like women and students of color. The Knowledge Assessment can be seen in Appendix A. It contains 10 multiple choice and five essay questions to determine student knowledge about the basics of the course. The Attitudinal Assessment was taken from a previously validated metric of engineering undergraduates' attitudes towards engineering and self-efficacy assessment on those skills [14-15]. It can be seen in Appendix B.

On the first day of class (for undergraduates) or before the first session (for high school students), this survey was distributed and collected by a sociology graduate student, so that respondents would not feel that their answers would prejudice the professor towards them one way or another. After removing unique identifiers from the survey, the engineering professors graded them. Each professor was responsible for the same questions at Time 1 (before the course) and Time 2 (after the course) so as to maintain as much uniformity in grading as possible. No grade was attached to the survey, as per ethical guidelines, but students were told to "do their best."

Research Questions:

Thus, our research questions include: i) what is the knowledge growth about AM during this course? ii) does this differ by university? iii) does this differ by gender or race? iv) what are the best ways to make this course portable to other universities?

Results:

Last year (2018), in the first year of the course, results indicate a statistically significant improvement in knowledge for all students (see tables in Appendix C). This was particularly true for women and first-generation college students, which may indicate the promise of AM courses in decreasing the female and first-generation dropout rate in engineering. Using a content knowledge assessment (seen in Appendix A) we designed and implemented at Time 1 and Time 2, we measured change in knowledge via multiple choice and essay questions (range 0-45). Through a paired samples t-test, we conclude that there was a statistically significant positive change at every university ($p<.01$). Also using a t-test, we conclude that there was a statistically significant positive change for every subgroup measured, including males, females, white students, students of color, first-generation, and non-first-generation students ($p<.01$).

Attitudes towards engineering and self-efficacy perceptions also differed after the class, but in varying ways by demographic subgroups and university. There are different total numbers for the content assessment and perceptual assessment because some students chose not to complete both. Overall, students changed their minds somewhat about what is important in engineering, generally assigning higher importance levels to job-related skills at the end of the course than they did at the beginning. The largest shift can be seen in students' self-efficacy levels. All three constructs showed statistically significant gains ($p<.01$) and nine of the 11 individual skills showed statistically significant gains. This is promising because high levels of belief in self-efficacy correlate with increase tenure in engineering and career persistence, particularly in women and students of color. The largest statistically significant gains were found in teamwork and technical skills, which reflects the content and pedagogical methods of the course. Students were not shown their original scores at Time 2 data collection in order to remove bias.

For 2019, we have just finished collecting the Time 1 data, so do not yet have results for this year. For the next draft, we plan to include the 2019 data and see if there are statistically significant changes between 2018 and 2019, as well as determine if the same pattern of results holds. That is, we wish to determine if females still have a larger increase in knowledge than males and if first-generation college students have a larger increase in knowledge than non-first-generation college students. We will also have enough data from the high school students by the end of the semester to be able to run a quantitative analysis with sufficient power on their results.

In regard to research question IV above, we also are using the current writing of a textbook and construction of a Google Classroom to test out different strategies for making this course portable. We will have results by the end of the semester.

Resources

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Appendix A – Content Knowledge Metric

(1) Which kinds of materials can be fabricated by additive manufacturing processes (more than one answer)?

(A) Metals (B) Ceramics (C) Plastics (D) Composites

(2) 3D printable models may be created with a computer-aided design (CAD) package, and __________ is one of the most common file types that all the 3D printers can read and print.

(A) .sldftp (B) .dwg (C) .stl (D) .cad

(3) Which one of following processes used filament as starting material (feedstock)?

(A) Fused Deposition Modeling (FDM) (B) Selective Laser Melting (SLM)

(C) Stereolithography (SLA) (D) Laser Engineered Net Shaping (LENS)

(4) Which one of following processes would not be used in additive manufacturing fabrication?

(A) Extrusion (B) Fusion welding

(C) Polymerization (D) Machining

(5) Which of the following process has the lowest unit manufacturing cost?

(A) Fused Deposition Modeling (FDM) (B) Selective Laser Melting (SLM)

(C) Stereolithography (SLA) (D) Laser Engineered Net Shaping (LENS)

(6) You can recycle many plastic containers and extrude them into reels of filament used on Fused Deposition Modeling (FDM) 3D printers. These plastics are __________.

(A) thermoplastics (B) thermosets (C) photopolymers

(7) In 2015, the FAA cleared the first 3D printed part to fly in a commercial jet engine from GE. It is the housing for the compressor inlet temperature sensor as shown in this right figure. By layering powered metals that are melted and fused together through a process known as __________ the piece are welded together as one and come out five times stronger than its predecessor.

(A) Selective Laser Melting (SLM)

(B) Fused Deposition Modeling (FDM)

(C) Stereolithography (SLA)

(D) Laser Engineered Net Shaping (LENS)

(8) Which of the following additive manufacturing solutions applies an ultraviolet light to a liquid polymer to change it into solid plastic?

(A) Selective Laser Melting (SLM) (B) Fused Deposition Modeling (FDM)

(C) Stereolithography (SLA) (D) Laser Engineered Net Shaping (LENS)

(9) Post processing _______________ be used after AM fabrication?

(A) has to (B) doesn't have to

(10) Generally speaking, the AM fabricated parts have better surface roughness than machined parts. Please judge this statement.

(A) True (B) False

(11) In your opinion, what is additive manufacturing or 3D printing?

(12) Please talk about how the part would be built from 3D model to 3D part in additive manufacturing processes?

(13) Discuss the current benefits and limitations of 3D printing; give examples of areas where 3D printing is perfectly fitting in and some are not niche markets now.

(14) Current AM/3D printing technologies all build a part in a layer-by-layer fashion. Do you think it is the perfect way to build every part? What can you imagine as a "true AM/3D printing technology", why it is better than the state-of-the-art now?

(15) Biofabrication is strongly reliant on 3D printing to accurately place cells, matrix and materials in position for tissue engineering. These constructs can be used as testing systems for new drug discovery, understanding cell biology and for replacing tissues and organs that are damaged through injury or disease. As you can image, bones, tissues, and organs, especially for a specific individual, cannot be drawn easily using an engineering CAD package, can you think of any approach to generate these digitalized and individualized 3D printable files?

Appendix B – Attitudinal Metric and Demographics:

(16) Please circle your department and institute.
(A) ME (B) IE or IMSE (C) Others _______

(17) What is your classification? Please circle: Freshman Sophomore Junior Senior

(18) What is your sex? _______

(19) What is your race? _________

(20) Are you a first generation college student? Yes No

(21) Please rank each of the skills listed below in order of how important you believe they are for an engineer to have (1 is least important, 5 is most important). Then, on the same 1-5 scale, rate yourself on how well developed you are in that skill (1 is not developed at all, 5 is fully developed).

	Importance for Engineering	**Self-Development Score**	**Have you improved in this skill since the beginning of the semester? Y/N**
Communication Skills, including Listening Skills			
Ability to Work Effectively in a Team/Group			
Math and Science Skills and Knowledge (not including computer skills)			
Ability to be Creative			
Problem Solving Skills			
Leadership and Management Skills			
Computer Skills (including programming and modeling)			

Technical Skills and Knowledge			
Time Management Skills (including punctuality)			
Analytical Skills			
Orderliness and Organizational Skills			
Attention to Detail			

Appendix C – 2018 Results:

Content Knowledge Statistics:

Table 1: Content Knowledge Averages and Differences at Times 1 and 2, by University

	Time 1	Time 2	Change (of matched pairs)
TTU	N=20, $\bar{X}$=15.55	N= 16, $\bar{X}$ =34.5	16 matched pairs, +18.95***
KSU	N=25, $\bar{X}$ =17	N=23, $\bar{X}$=33.5	23 matched pairs, +16.5***
CSUN	N=24, $\bar{X}$ = 14.25	N=20, $\bar{X}$=28.45	20 matched pairs, +14.2***
Aggregate Total	**N= 69, $\bar{X}$ =15.62**	**N=59, $\bar{X}$ =32.07**	**59 matched pairs, +16.45*** **

* p<.10 ** p<.05 ***p<.01

Table 2: Content Knowledge Averages and Differences at Times 1 and 2, by Demographics

	Time 1	Time 2	Change (of matched pairs)
Males (Time 1 N= 50)	$\bar{X}$= 15.6	$\bar{X}$ = 31.3 (N=43)	43 matched pairs, +15.7***
Females (Time 1 N=18)	$\bar{X}$ = 15.94	$\bar{X}$ = 34.125 (N=16)	16 matched pairs, +18.185***
Industrial Engineering (Time 1 N= 40)	$\bar{X}$ = 16.03	$\bar{X}$ = 33.7 (N=35)	35 matched pairs, +17.67***
Mechanical Engineering (Time 1 N=11)	$\bar{X}$ = 20.82	$\bar{X}$ =34.7 (N=10)	10 matched pairs, +13.878***
White Students (Time 1 N=43)	$\bar{X}$ = 16.74	$\bar{X}$ = 33.44 (N=41)	41 matched pairs, +16.7***
Non-white Students (Time 1 N= 23)	$\bar{X}$ = 14.3	$\bar{X}$ = 28.94 (N=18)	18 matched pairs, +14.64***
First Generation College Students (Time 1 N=18)	$\bar{X}$ =13.22	$\bar{X}$ =30.62 (N=13)	13 matched pairs, +17.44***
Non-First Generation College Students (Time 1 N=50)	$\bar{X}$ = 16.58	$\bar{X}$ =33.02 (N=45)	45 matched pairs, +16.44***

* p<.1 ** p<.05 ***p<.01

Perceptual and Self-Efficacy Statistics:

IMPORTANCE TO ENGINEERING		Time 1				Time 2				Change			
		TTU N=16	CSUN N=18	KSU N=21	TOTAL N=54	TTU N=16	CSUN N=18	KSU N=21	TOTAL N=54	TTU	CSUN	KSU	Total
Job Related Skills	Analytical Skills	4.67	4.53	4.4	4.5	4.53	4.65	4.65	4.6	-.13	+.12	+.15**	+.1
	Computer/Technical Skills	3.73	4.52	4.25	4.18	4.33	4.76	4.25	4.44	+.6**	+.24	0	+.26**
	Math/Science Skills	4.44	4.33	4.285	4.35	4.125	4.67	4.285	4.36	-.3125	+.34	0	+.01
	Creativity	4	4.35	3.95	4.11	3.87	4.76	4.15	4.27	-.13	+.41**	+.2	+.16*
	Problem Solving	4.73	4.71	4.75	4.73	4.8	4.76	4.9	4.84	+.07	+.05	+.15	+.11*
	Overall Job Related	*4.35*	*4.46*	*4.25*	*4.34*	*4.28*	*4.62*	*4.41*	*4.44*	*-.07*	*+.16*	*+.16**	*+.1**
Interpersonal Related Skills	Leadership	4.13	4.47	3.85	4.13	3.87	4.35	3.95	4.04	-.27	-.12	+.1	-.09
	Communication	4.5	4.82	4.64	4.62	4.5	4.89	4.67	4.69	0	+.07	+.03	+.07
	Teamwork	4.48	4.52	4.68	4.55	4.3	4.94	4.67	4.65	-.18	+.42**	+.01	+.1
	Overall Interpersonal	*4.29*	*4.57*	*4.42*	*4.43*	*4.2*	*4.75*	*4.43*	*4.46*	*-.09*	*+.18**	*+.01*	*+.03*
Life and/or Professional Skills	Time Management	4.4	4.65	4.45	4.51	4.27	4.71	4.45	4.49	-.13	+.06	0	-.02
	Orderliness and Organizational Skills	3.73	4.59	3.75	4	4.07	4.76	3.65	4.11	+.33**	+.17	-.1	+.11
	Attention to Detail	4.2	4.91	4.6	4.61	4.47	4.94	4.75	4.71	+.27	+.03	+.15	+.1
	Overall Life/Professional	*4.11*	*4.72*	*4.27*	*4.37*	*4.27*	*4.8*	*4.28*	*4.44*	*+.16**	*+.08*	*+.01*	*+.07*

* p<.10 ** p<.05 ***p<.001

SELF-EFFICACY		Time 1				Time 2				Change			
		TTU N=16	CSUN N=18	KSU N=21	TOTAL N=54	TTU N=16	CSUN N=18	KSU N=21	TOTAL N=54	TTU	CSUN	KSU	Total
Job Related Skills	Analytical Skills	4.2	4	3.6	3.89	4	4.18	3.9	4	-.2	+.18	+.3*	+.11
	Computer/Technical Skills	3.47	3.76	3.45	3.55	3.73	4.35	3.75	3.93	+.27	+.59**	+.3*	+.38***
	Math/Science Skills	3.8	3.88	3.75	3.78	3.93	4.38	3.85	4.03	+.13	+.5**	+.1	+.25**
	Creativity	3.07	4.35	3.75	3.75	3.8	4.35	3.7	3.95	+.73***	0	-.05	+.2*
	Problem Solving	3.87	4.24	3.9	3.95	4.13	4.53	4.05	4.24	+.26*	+.29*	+.2	+.29**
	Overall Job Related	*3.53*	*4.02*	*3.65*	*3.72*	*3.87*	*4.35*	*3.76*	*3.98*	*+.34***	*+.33**	*+.04*	*+.26****
Interpersonal Related Skills	Leadership	4.07	4.18	3.75	3.98	4.4	4.12	4.15	4.24	+.33	-.06	+.4***	+.26**
	Communication	4.05	4.14	4.08	4.09	4.3	4.3	4.19	4.27	+.25**	+.16	+.1	+.18*
	Teamwork	3.8	4.33	4	4.05	4.37	4.53	4.1	4.52	+.56*	+.2	+.1	+.46***
	Overall Interpersonal	*3.91*	*4.22*	*4.02*	*4.04*	*4.33*	*4.36*	*4.32*	*4.34*	*+.42****	*+.14*	*+.3***	*+.3****
Life and/or Professional Skills	Time Management	4.13	4.12	4.1	4.13	4.4	4.44	4.1	4.32	+.27	+.32	0	+.19*
	Orderliness and Organizational Skills	3.93	4.47	3.55	3.96	4.07	4.29	3.9	4.11	+.14	-.18	+.35**	+.15
	Attention to Detail	3.8	4.65	3.9	4.1	4.33	4.65	4.25	4.38	+.53***	0	+.35**	+.28***
	Overall Life/Professional	*3.96*	*4.41*	*3.85*	*4.06*	*4.27*	*4.46*	*4.08*	*4.27*	*+.31***	*+.05*	*+.23***	*+.21****

* p<.10 ** p<.05 ***p<.01