The Development and Implementation of an Interdisciplinary Additive Manufacturing for Healthcare Innovation Course

Dr. Ismail Fidan, Tennessee Technological University

Currently, Dr. Fidan serves as a Professor of the Department of Manufacturing and Engineering Technology at Tennessee Technological University. His research and teaching interests are in additive manufacturing, electronics manufacturing, distance learning, and STEM education. Dr. Fidan is a member and active participant of SME, ASEE, ABET, ASME, and IEEE. He is also the Associate Editor of IEEE Transactions on Components, Packaging, and Manufacturing Technology and International Journal of Rapid Manufacturing.

Dr. Melissa Geist, Tennessee Technological University

Dr. Melissa Geist is a Professor of Nursing as well as a nationally board certified Family and Pediatric Nurse Practitioner. Dr. Geist received her doctorate at Peabody College of Vanderbilt University. She completed a Post-Doctoral Fellowship with the NSF funded VaNTH Engineering Research Center (a collaboration between Vanderbilt, Northwestern, The University of Texas and Harvard Universities) where she developed and implemented Legacy Cycles as part of curricular reformation in Biomedical Engineering aimed at increasing flexible knowledge and adaptive expertise of students. In her classes, nursing students engage in critical reasoning and clinical decision making via Legacy Cycle modules on complex topics such as management of anticoagulants, and interpreting arterial blood gas values. She has received the Outstanding Faculty award, the Award for Innovative Instruction, and the Leighton E. Sissom Award for Innovation and Creativity. Dr. Geist serves on the strategic committee for the newly designed Innovation and Entrepreneurship (I&E) Certificate offered at Tennessee Technological University. The focus of the I&E program is to provide students the opportunity to develop entrepreneurship and innovation skills through problem solving, creativity, working with a team and practicing effective strategies for meeting needs within the increasingly competitive global marketplace. Dr. Geist served as the faculty mentor for two nursing students who were University Innovation Fellows (UIF) with the National Science Foundation Epicenter at Stanford University (only three nursing students nationwide have been selected for the UIF program).

Dr. Yunbo Zhang, Rochester Institute of Technology

Dr. Yunbo Zhang is currently an Assistant Professor in Department of Industrial & Systems Engineering at Rochester Institute of Technology (RIT). Dr. Zhang's research focuses on investigating computational methods for advancing design and manufacturing towards automation, intelligence, intuitiveness and innovation. Dr. Zhang is a member and active participant of ASME, IEEE, ACM, and IISE. He also actively serves as reviewers for more than 25 journals and conferences in design and manufacturing area. From 2014 to 2015, he served as Guest Editor of the special issue of Computer-aided Design and Applications on "Technologies for Human Centric Free-form Products".

Dr. George Chitiyo, Tennessee Tech University

George Chitiyo, Ph.D., is a Professor of Educational Research and Evaluation at Tennessee Tech University. He teaches courses in research methods, statistics, and program evaluation. His research interests include the psychosocial aspects of HIV/AIDS in Southern Africa as well as economics of health and higher education both in the U.S. and in Southern Africa. He is involved in designing and implementing evaluation initiatives of several educational programs and interventions in PreK-12 and higher education settings.

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Abstract

This paper reports the unique aspects of a newly developed and implemented, interdisciplinary Additive Manufacturing for Healthcare Innovation course. The authors discuss the unique aspects of the course, assessments of student learning, the effectiveness of working in interdisciplinary teams, and students' perceptions of the course. An evaluation of the course was conducted by an external evaluator who was not involved in the teaching of the course. The evaluation addressed the key objectives of the course, skills that the instructors wanted students to learn, as well as the delivery methods of the course. This paper provides the original instructional delivery components of the course and the findings of the course evaluation.

Background

Additive Manufacturing (AM), also known as 3D Printing, is currently impacting the future of almost every industry. Already estimated to be a $12 billion industry, AM has quickly transitioned from a new way of prototyping to an end-use production method. Several companies are manufacturing consumer and medical products using AM rather than through conventional manufacturing methods [1]. Large companies such as General Electric, Boeing, Caterpillar, John Deere, Adidas, BMW, Porsche, and all the armed forces, are spending millions, and even, billions of dollars on AM. According to a recent study, the true global impact of AM will be similar to that of the Internet, once AM becomes more accessible to everyone [2].

The medical field is one of the fastest growing application areas of AM and the technology is already in use in the production of equipment, tools, and accessories [3]. Either as a better way to manufacture or enabling patient-specific devices, AM has distinct advantages in medicine. The use of AM in healthcare applications has attracted considerable interests over the past decade for its unique benefits in reducing healthcare costs, and meanwhile increasing healthcare quality. In particular, AM is uniquely suitable for medical device customization in relatively short time frames [4].

Considering the above given facts, the faculty at Tennessee Tech University created a unique AM course. In the past, the faculty have developed and practiced a few AM related course components and innovations [5]-[7]. However, this was the first time they have developed such a comprehensive and innovative interdisciplinary course. The course, taught in a 15-week semester, brought mechanical engineering, engineering technology, and nursing majors together for interdisciplinary inquiry-based learning. The course involved primarily challenge-based learning, but also included lectures, team-based reiterative design, and teaching with technology. Each interdisciplinary four-person team of students identified a health care challenge, such as designing a new pole on which to hang various intravenous fluids in the hospital. Once the students identified the problem, they interviewed stakeholders (such as nurses or paramedics), sketched solutions, and used AM and low budget prototyping to develop devices addressing the challenge.

One of the essential parts of the course was to deliver the innovation and entrepreneurship components of NSF's I-Corps model to the teams. Two faculty members from the NSF I-Corps Site provided training on key aspects of I-Corps, including business plan development and the importance of customer discovery [8]. Student teams also benefited from video conferences with a number of industrial experts and consultants. Each student team presented their challenge statement and discussed possible solutions with the industrial experts. These experienced AM experts from industry helped troubleshoot the teams' design ideas leading to improved final prototypes. Overall, the course was a success in terms of students' interdisciplinary teamwork skill development and creative problem-solving using AM.

This novel pedagogical approach contains several best practices. This paper will report the development and implementation steps of this original course. The evaluation results will also be provided to reflect the pros and cons of the course from the students' viewpoint.

Unique Aspects of the Course

The objective of the course was to help students from multiple disciplines understand the latest developments and critical challenges of AM technologies, and provide students with related techniques and practical experience in developing innovative AM processes and applications. The course was focused on the use of AM technologies to improve health outcomes. As demonstrated by the survey data, this interdisciplinary, project-based course challenged students to think outside of their normal professional boundaries (nursing and engineering) to develop viable solutions to authentic healthcare challenges. The following section will provide several best practices provided throughout the course.

Interdisciplinary Teamwork:

The course professors provided several lectures on design for AM, AM processes, and post-processes. At the beginning of the semester, five interdisciplinary teams were established where each team would work on a health-related course project throughout the semester. All members of the team developed and signed a teamwork contract to ensure accountability of each team member. Throughout the semester, teams provided several presentations to debrief their progress in the tasks and deliverables of their project. In each presentation, constructive feedback was provided to each team. The nursing students helped the teams identify real world challenges in healthcare by sharing their nursing experiences with their teams. For example, one nursing student who worked as a Patient Care Assistant (PCA) in a busy trauma center discovered that the poles that are used to hang fluids cause falls, are hard to maneuver and trap wires and tubing in the base of the structure. The team of nursing and engineering students redesigned the pole to include a covering at the base, wheels that pivot with ease, and a manifold to organize tubing. Figure 1 shows this team's project. The team 3D printed a proof-of-concept model that they shared with nurses and other hospital stakeholders who in turn made suggestions for redesign. This reiterative process, with end-user input was a hallmark of the course and led to more viable projects.

Project based, Inquiry based Learning:

The faculty used the Legacy Cycle, a challenge-based approach to learning, to guide the course activities [9]. The Legacy Cycle frames opportunities for innovation around a challenge statement, provides a structure for divergent idea generation, embeds multiple perspectives, and encourages reiterative design. The Table 1 given below demonstrates how the Legacy Cycle provided structure for the interdisciplinary teams as they moved from problem identification to final prototype design.

Table 1: Legacy Cycle Framework of the Additive Manufacturing for Healthcare Innovation Course

Additive Manufacturing for Healthcare Innovation Course Legacy Cycle		
Legacy Cycle Phases	General Description [9]	Specific Course Activities
Challenge Question	A deliberately open-ended question or task that captures learners' interest and engages them to confront preconceptions and to investigate their current level of knowledge.	Through interviews with users and stakeholders, the interdisciplinary teams identified an opportunity to improve health outcomes using AM principles.
Generate Ideas	A brainstorming activity in which learners display current knowledge, ideas, and preconceptions.	The interdisciplinary teams responded to prompts such as "What do you already know related to the identified challenge?" "What additional information or skills will your team need to learn to accomplish this task?"
Multiple Perspectives	Statements by stakeholders in the challenge to provide insight into the varying features of the task without providing a solution.	Teams interviewed stakeholders (i.e. nurses, paramedics) to develop empathy with potential users.
Research and Revise	Students participate in activities to help them focus on the most important aspects of the challenge.	Teams presented initial design ideas to AM experts in video conference. The teams participated in a think-pair-share activity by responding to the prompt: "Based on the multiple perspectives, and research and revise activities, are there changes that you would make to your original thoughts/ideas/perceptions generated earlier."
Test Your Mettle	Formative assessments that provide a framework for learners to measure what they understand and to identify opportunities for improvement.	Multiple activities for low-budget prototyping and reiterative design. Teams met with faculty members, presented design ideas and returned to the maker space to 3D print prototypes with design improvements.
Go Public	The final assessment of what the learners know after progressing through the Legacy Cycle.	Using a PechaKucha format, teams presented the journey from challenge to final prototype design. Stakeholders, prototype end-users, and interested community members (nursing advisory board members, hospital nurses and administrators, etc.) attended the presentations.

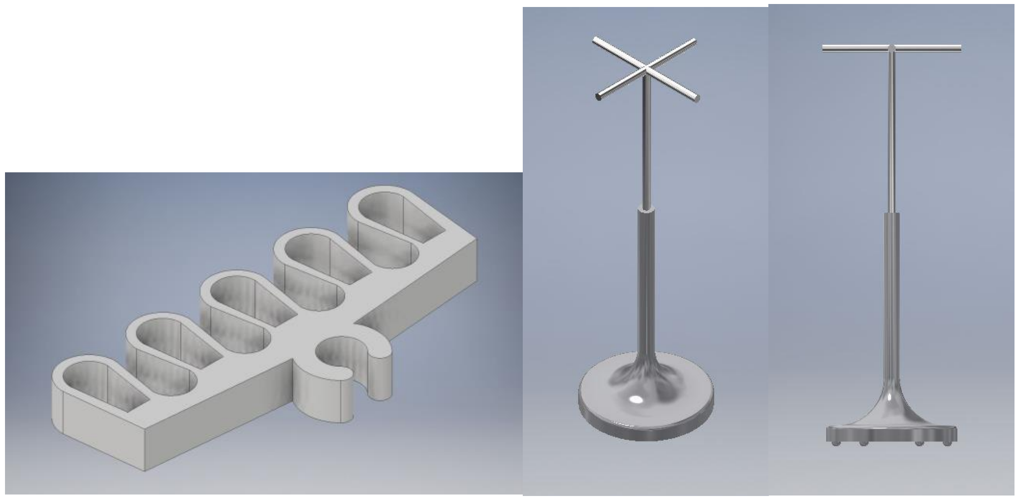

Figure 1: A sample interdisciplinary team project: IV Pole redesign to increase safety, maneuverability, and stability

Industrial Support:

Student teams were able to get mentorship from an industrial mentor with more than 20 years of industrial experience in design, simulation and fabrication. The mentor provided his expertise so that student teams could get quick and hands-on help and support to their projects and course outcomes.

Innovation and Entrepreneurship:

Two weeks of the course were arranged for the delivery of the customer discovery, commercialization, and marketing aspects of a newly developed product. In order to deliver these timely subject matters, the NSF I-Corps Site’s instructional team provided knowledge and training related to the Lean Launchpad approach to innovation and entrepreneurship. The leader from a local innovation and entrepreneurship small business development center challenged the teams to consider elements such as value proposition and distribution channels for their projects. These robust discussions forced students to think deeply about the viability of their prototypes in terms of commercialization.

Teaching with Technology:

The entire course was managed via the Desire to Learn (D2L) course management system. Project submissions, assessments, team formation and grading tasks were handled via D2L. Student teams had a chance to present their projects and receive guidance and support from several nationally-known experts at several state and federal agencies who hold academic, research, and administrative positions. This interactive discussion section was maintained via the ZOOM webinar tool and it was positioned in the middle of course schedule so that teams could receive more troubleshooting on the problems they were facing.

Eagle Works:

Eagle Works is an innovation and entrepreneurship competition that encourages and supports the student entrepreneurship at the university level. Each team focused on developing an innovative business idea, writing a business plan, and pitching their idea to a panel of judges for a chance to win several awards [10]. One of the focuses of the course was also to prepare the student teams for this competition.

Evaluation of the Course

Students' perceptions and experiences in the course were assessed by an external evaluator. A survey instrument was developed in early March and administered in April 2018 after the participants had a full semester to identify a health care problem, design, and prototype. Students' selected verbatim responses are italicized.

A total of 26 students responded to the evaluation survey. The distribution of students is given in Table 2. They included students from the following majors: Mechanical engineering, 40% (n = 10); Engineering Technology, 28% (n = 7); Nursing, 20% (n = 5); and Other, 12% (n = 3). The classification of the students was as follows: 88% (n = 21) seniors, 8% (n = 2) juniors, and 4% (n = 1) sophomores.

Table 2: Distribution of Students by Gender, Major, and Classification

Major	**Male**	**Female**	**Total**
Mechanical Engineering	88.9% (n = 8)	11.1% (n = 1)	100.0% (n = 9)
Engineering Technology	85.7% (n = 6)	14.3% (n = 1)	100.0% (n = 7)
Nursing	40.0% (n = 2)	60.0% (n = 3)	100.0% (n = 5)
Other, specify	66.7% (n = 2)	33.3% (n = 1)	100.0% (n = 3)
Total	75% (n = 18)	25% (n = 6)	100% (n = 24)
Classification	**Male**	**Female**	**Total**
Sophomore	0%	100% (n = 1)	100% (n = 1)
Junior	50% (n = 1)	50% (n = 1)	100% (n = 2)
Senior	85% (n = 17)	15% (n = 3)	100% (n = 20)
Total	74% (n = 18)	22% (n = 5)	100% (n = 23)

Students were presented with a series of statements that pertained to how they worked during the course. Table 3 shows the percentages of students who either agreed or strongly agreed to each of the statements.

Table 3: How the students worked during the course

	Percent of students agreeing to the statement
The process of defining the problem within my team was simple.	70% (N = 26)
My team worked together well to define the problem.	96% (N = 25)
My team explicitly followed the engineering design to define the problem.	53% (N = 26)
My team explicitly followed the Nursing Process: Assess, Diagnose, Plan, Implement, Evaluate (ADPIE) to define the problem.	31% (N = 26)
My team explicitly followed the engineering design to develop a solution.	65% (N = 26)
My team explicitly followed the Nursing Process (ADPIE) to develop a solution.	31% (N = 26)
My team did its best to come up with a fabricated end product.	85% (N = 26)
My team solicited information from a number of sources to identify the central project problem and to solve it.	80% (N = 26)

The intended collaboration among students of different backgrounds occurred throughout the semester. Students from engineering worked alongside their nursing counterparts to achieve the desired outcomes. The following are some of the verbatim students' statements by the students:

- After identifying the problem and researching our topic it was easy to develop a user-friendly prototype that could be used throughout the medical field. Our issue was edema and some of our team members had experience with measuring edema and therefore was able to work with the engineers of the group to create a simple design that can accurately measure the depth.
- We decided on a problem, did research on the topic to find a solution, met with nurses to figure out if our problem was an actual problem, and then designed our solution.
- We identified key design features needed for a successful prototype differentiated from the competition. Feedback from interviews with potential customers went into the iteration loop and a final design materialized.
- We conducted interviews, concept creation, more interviews, cad creation, modifications, and finally, we printed.
- First research, then conceptual design, followed by interviews, to 1st prototype, 2nd prototype/final prototype
- We discussed the problem and moved forward to find the solution.
- Once the problem was identified we met for multiple brainstorming sessions and slowly added onto our idea until we had our first-generation prototype. Then we took the idea to the CRMC rehab center to receive the feedback from the physical therapist on how we can improve our design. Finally, we printed our design in 3D.
- Based on interviews, we decided what ideas fit what roles and proceeded.
- Once the problem was found we did interviews that reassured our problem was a need.
- We retrieved information from interviews and online, then we designed.
- We identified issues and improvements with each potential prototype idea and as we got new info from interviews, patents, etc.
- When we finally nailed down the problem, we started the design process. Our team used CAD, the maker space and 3D printing.
- We decided our initial ideas, performed a literature review, performed interviews, and then decided on our final prototype.

For the following items, students were presented with a series of statements pertaining to what they learned during the course. Tables 4, 5, and 6 show the percentages of students who either agreed or strongly agreed to each of the statements.

Table 4: What the students learned—specific aspects

	Percent of students agreeing to the statement
The course helped me learn the current standing of Additive Manufacturing.	23% (*N* = 26)
The course helped me learn the fundamentals and applicability of the Additive Manufacturing processes.	43% (*N* = 26)
The course helped me learn the fundamentals and applicability of additive Manufacturing processes to healthcare.	51% (*N* = 26)
An opportunity to learn the post-processing techniques of any additively manufactured workpiece.	35% (*N* = 26)
The course helped me understand the latest developments in 3D Printing/Additive Manufacturing workpiece.	23% (*N* = 26)
The course helped me understand the critical challenges of 3D Printing/Additive Manufacturing technologies.	44% (*N* = 25)

Table 5: How the course helped the students

	Percent of students agreeing to the statement
The course helped me learn to work within a teamwork environment.	81% (*N* = 26)
The course helped me to practice and improve my communication skills.	76% (*N* = 26)
The course helped me to practice and improve my collaboration skills.	81% (*N* = 26)
The course helped me to understand innovation and entrepreneurship skill sets.	66% (*N* = 26)
The course helped me to understand the fundamentals of design for Additive Manufacturing.	38% (*N* = 26)

Table 6: How beneficial was each of the following course delivery methods in helping you learn the course content?

	Very beneficial
Lecture	12% (*N* = 26)
Group discussion	46% (*N* = 26)
Critical thinking activities	31% (*N* = 26)
Case presentations	42% (*N* = 26)
Simulation lab scenarios	19% (*N* = 26)
Webinar Presentation with Experts on March 20th	42% (*N* = 26)
Project based learning	64% (*N* = 25)

Finally, the following list provides the compilation of students' feedback on their choices to the best aspects of the course.

- Teamwork
- The 3D printing method learning
- Teamwork
- The open-ended nature of the class. There is no ceiling for the students and there is no limit to how much they can accomplish.
- Exposure to different areas of education
- Working together in a group and coming together to create something as a team.
- No exams
- Snacks!
- The fact that we have so much freedom through the design process.
- Cradle to grave design
- The faculty is good; you have all-stars on the team.
- Learning entrepreneurial skills
- The expertise of the faculty who taught the course, and the exposure to a wide range of professionals in different fields
- Project based learning provided good insight into nursing applications.
- Project based course
- Working as team
- Interdisciplinary groups
- Teamwork/creativity/open challenges/ability to pursue ideas
- Having a class with Dr. Geist
- Loved the professors and the concept of this course
- Getting to develop and design our own project.

Lessons Learned

Even though the faculty considered the course a success based on the data collected from the outside evaluator and the student comments, there is always room for improvement. In future iterations of the course, the faculty plan to make a stronger connection between AM and healthcare delivery. The students left with a basic understanding of how AM can be used to improve health outcomes; however, we believe that AM will fundamentally change healthcare delivery and this should be emphasized in the future. Inviting guest speakers and showing videos of current AM applications at the beginning of the course will demonstrate to the students the power of this emerging technology. We also discovered that students became attached to their initial design ideas and were resistant to criticism. One of the most uncomfortable class periods involved a guest speaker from a local entrepreneurship launch pad who challenged the students to consider as many different design options as possible that would solve the problem the team identified. The students bristled at the notion that their original designs were not adequate. Embedding activities to help students understand that failure is a valuable part of the design process will help them grow as innovators and problem-solvers.

Conclusions

The number of the AM related research projects, innovations, and developments is growing every day. Several companies are starting to recognize the benefits of AM offers in terms of speed, simplicity, and cost. In this sense, several universities offer AM courses in order to train the future workforce to answer the need of advancing industry. This paper highlighted critical aspects of the newly developed AM for Healthcare Innovation course, which brought together nursing and engineering students to work as teams for new device design to improve health outcomes. The unique components of the course and the feedback received from the enrolled students were reported. Based on this initial development and implementation, the course professors plan to make improvements and advance the deliveries of the course in the near future.

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