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Simulation and Interactive Digital Tools to Support Teaching Engineering Manufacturing Processes Course

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ORIGINAL RESEARCH

Abstract
Abstract— Introduction of Manufacturing Processes is one of the core courses in most mechanical engineering, manufacturing engineering, and industrial engineering programs. According to students' feedback for this course, as well as similar courses offered at different engineering programs, the course is time-intensive, involves no critical thinking, requires limited class participation, and is not well connected with real-world manufacturing problems.

The suggested teaching approach is developed to include several computer-based learning components that can help in creating an active/passive/constructive learning environment for the students. A simulation-based project is used to strengthen constructive concept-based learning and critical thinking for the students and support laboratory analysis. Besides, several online quizzes were developed using a pool of questions related to each topic. Assessments and survey results are used to evaluate the performance of the suggested teaching approach. In addition, students' micro-lectures are used to improve lifelong learning skills and create an interactive teaching environment with the instructor and other students.

The learning outcomes from the application of the computer aided instruction approach are reflected through the students' successful completion of the project activities; in addition, the students learned how to use a single computer-aided design (CAD) package to engage in an advanced design and manufacturing analysis which is valued in industry as well as to solve difficult engineering problems. Besides that, the students gained lifelong learning and communication skills through micro-lecture preparations and presentations. In this work, in addition to the students' performance in the course assignments, a pre- and post-course evaluation is used to asses and evaluate the success in achieving course learning outcomes based on the suggested teaching and learning components. Also, the learning modules related to the casting processes, the product assembly processes, and tolerances analysis topics are presented and discussed.

Keywords: Computer Aided Instruction, Engineering Education, Project Based Learning

Related ASEE Publications

[8] B. Ansaf and N. Jaksic. "Teaching Mechanical Design for Mechatronics Engineering Students Using a Project-based Sequential Learning Approach,". In *ASEE Annual Conference Proceedings*. ASEE, June 2018.

[12] B. Ansaf and N. Jaksic. "Teaching Undergraduate Manufacturing Course using a Design-based Teaching Approach,". In *ASEE Annual Conference Proceedings*. ASEE, June 2019.

[1] D. Wendell. "Teaching Undergraduate Manufacturing in a Flipped Classroom,". In and others, editor, *ASEE Annual Conference and Exposition, Conference Proceedings*, June 2018.

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1 Introduction

Instructors are always trying to find a passionate way to teach their courses to support student's success efficiently and effectively. Furthermore, the continuous increase in the needs for new technical and nontechnical skills in the modern work environment represents another pressure factor on the universities to update student's learning outcomes to meet the demand of the contemporary industry and business to keep the qualified workers current. Thus, the teaching methods need to be updated continuously to reflect the direct and indirect changes in the learning and the work environment. In general, during the past few decades, engineering education became more focused on hands-on project-based teaching approaches, used more interactive, open-ended problems, and required more feedback on the problem-solving process that is proven to be more effective and can lead to increased student learning [1] .

Several teaching approaches were implemented to improve student's learning outcomes by integrating active/passive learning and real-life projects. For example, Graham et al. [2] used the Paul-Elder framework of critical thinking to define and operationalize critical thinking for the Electrical and Computer Engineering program students. Students are taught explicitly the methods of critical thinking followed by explicit critical thinking exercises in the introduction to engineering course to prepare students to embrace more elaborate, discipline-specific, critical thinking required of them in future courses. At sophomore, junior and senior levels, courses were selected to emphasize critical thinking and professional ethics. The students were encouraged to use critical thinking skills to analyze requirements and constraints which would apply for advanced real-world problems. Significant improvement in the critical thinking skills of students has been achieved through this sequence.

An integrated thinking approach is adopted by Katz [3] to bridge the educational gap between analytical and design thinking for mechanical engineering students. The suggested approach is implemented by reforming science engineering courses by stressing the physical interpretation of mathematical derivations to analyze and design simple mechanical devices; then, modifying project-based design courses to emphasize the analysis part of the creative design process. Positive feedback from the students suggests that integrated thinking might be successfully applied in many areas of mechanical engineering (ME) education to create continuous education patterns.

Simulation based learning (SBL) provides learners with interactive learning experiences and enhances students' motivation and performance [4]. Their research findings show "that the students perceived their basic psychological needs to be met and that SBL can potentially enhance self-determined motivation as well as improve learning in general." Another study [5] shows the value of using simulations to exercise reflective and descriptive thinking of students, given appropriate teacher support and careful technology selection.

Fredriksson [6] explored how and when to use software to support teaching in Engineering, Materials Science, or Design. He described how "a comprehensive digital tool for materials related teaching and learning can be introduced to students and used to promote engineering knowledge, skills and understanding in a modern and accreditation-friendly way." A software (CES Selector and Granta MI [7]) specifically developed for education was introduced in the first-year class on Materials Science and Engineering. The results show that the use of the software contributed to a number of students' learning outcomes.

A multi-levels sequential design project is used by Ansaf and Jaksic [8] to increase students learning outcomes in design analysis and critical thinking. The students implemented the required design modifications of a product in a systematic time-based procedure using traditional and nontraditional design tools like finite element analysis. Their results show an improvement in student engagement in the course topics and in critical thinking.

Okojie [9] claims that "in a highly competitive manufacturing industry, the total cost of design and manufacturing can be reduced and hence increase the competitiveness of the products if computers can integrate all working procedures. Computer-aided integration has, therefore, become an inevitable trend. Many industries have achieved a great deal of success between non-integrated and integrated systems."

Egelhoff et al. [10] described "a structured problem-solving approach which uses the students' understanding of free-body-diagrams, shear and moment equations, and energy methods. With the development of note-taking handouts supplied to the students, the structured analysis is led by the instructor using Castigliano's theory of internal energy. The problem formulation is kept general until the last step. Numerical integration can be performed in the software of the students' choice."; Egelhoff et al. [10] "found that using this approach accomplishes a richer, deeper understanding of design among our students and increases their confidence as indicated by our pre- and post-activity assessment."

The challenges, as well as the definition, characteristics, and educational objectives of flipped learning are introduced and summarized by Hwang et al. [11]. They identify why flipped learning has been adopted by so many educators. Among the reasons presented are:

1. *In-class activities and discussions.* This can increase teacher-student and student-student interactions, thus creating an active learning atmosphere that can improve students' learning motivation.
2. *Multimedia digital teaching materials.* These materials "are easy to save, manage, revise, and impart."
3. *Additional teaching strategies.* Advanced teaching strategies capable of promoting higher-order thinking abilities can be implemented.

Wendel [1] used a flipped classroom teaching approach to teach an intermediate undergraduate manufacturing class at the Massachusetts Institute of Technology. According to Wendel, the initial students' survey indicated that this intermediate-level manufacturing class was not related to "the real world," was not interesting, and was time-intensive. The feedback from students showed the class to mostly promote informative learning as opposed to concept-based learning and critical thinking. Implementation of the flipped-classroom approach included pre-recorded videos that were used to prepare the students for a lecture. Then students in pairs participated in challenges during the class time related to the lecture topic. The results showed increases in student participation during lecture time. Also, the students noted their preference for advanced scientific content in class.

According to students' feedback about their learning experience at the engineering manufacturing course, as well as the feedback on similar courses offered at other universities, the students mentioned the following: the course is time-intensive, involves no critical thinking, requires limited class participation, and is not well-connected with real-world manufacturing problems. Part of these drawbacks can be correlated to the traditional course curriculum and teaching style that mainly depend on the lectures for the manufacturing processes that are aligned and synchronized with the laboratory work (projects) to gain the required knowledge and skills.

The preliminary partial results about the design and implementation of a new teaching strategy for this course, and for similar technology-based engineering courses, had been presented elsewhere [12]. In this extended work presented here, we address the improvements in the teaching approach of an Engineering of Manufacturing Processes course for mechatronics and industrial engineering students at Colorado State University-Pueblo. The suggested teaching approach is developed to include several learning components that can help create an active/passive/constructive learning environment for the students. Computer-based simulation projects are used to strengthen constructive concept-based learning and critical thinking of the students. Online quizzes are designed and created to help students to improve their understanding of the basic definitions and concepts of traditional and nontraditional manufacturing processes. Additionally, students' micro-lectures are used to improve lifelong learning skills and create an interactive teaching environment with the instructor and other students.

Assessments and survey results are used to evaluate the performance of the suggested teaching approach during course implementation. In addition, at the end of the course, assessment survey results are used to evaluate the effects of the suggested teaching/learning activities on student learning outcomes.

2 Course Description

The manufacturing curriculum at the engineering program at Colorado State University- Pueblo consists of a two-course sequence: Engineering of Manufacturing Processes and Computer-Integrated Manufacturing (CIM). Both courses are structured so that enrollment is capped at 24 students per lecture and 16 students per lab section. Both courses are essential for the engineers dealing with any manufacturing discipline, whether working on a factory floor or in a design and management roles. In the Engineering of Manufacturing Processes course, students are exposed to introductory principles and concepts of traditional and nontraditional manufacturing. In general, a manufacturing processes course is a cornerstone foundation course in many engineering programs. The traditional objective of this course is to engage students with the principles and concepts of traditional and nontraditional manufacturing.

The course includes a description and basic analysis of manufacturing processes like product assembly, casting, metal forming, machining, welding, and semiconductor manufacturing. The engineering program at our university offers the Engineering of Manufacturing Processes course with lab (4 semester credit hours) for junior students including 3 contact hours of lecture and 2 contact hours of lab.

Prior to this course, the students had freshman and sophomore level courses and are expected to have the following prerequisites listed by topic:

1. Basic engineering drawing practices and tolerances
2. Basic physics concepts: velocity, acceleration, force, torque, energy, power, heat, fluid dynamics
3. Descriptive statistics, geometry, trigonometry, and calculus
4. Material properties: strain, stress, strain rate
5. Graphing 3D objects and system assembly using SolidWorks®,

The number of students in this course is capped at 24. The course is taught only once a year.

3 Course Implementation

The course is taught by first introducing each topic, then presenting examples, in-class assignments, and projects, and finally assigned homework. The class assignment sets are designed to allow students to practice and sharpen their problem-solving skills. The students are allowed to work in teams to solve in-class assignments during lab time.

3.1 In-class Simulation Projects and Exercises

A real-life engineering product with a challenging set of questions is used as an in-class project to improve critical thinking about different manufacturing operations beyond the classroom walls. To accommodate project analysis, the simulation tools in SolidWorks are used. For the dimensions and tolerances analysis in the assembly process, the students work on a design tolerances analysis problem to meet the required design specifications. The tolerances design for a linkage pivot is a modified and extended version from that given by Budynas et al. [13].

3.1.1 Project #1 Tolerances Design for a linkage pivot

A pivot in a linkage has a pin (Figure 1) whose dimension$x \pm a$is to be established. The thickness of the link clevis is 1.5$\pm$ 0.005 inches. The designer has concluded that a gap between g_{min} and g_{max} will satisfactorily sustain the function of the linkage pivot.

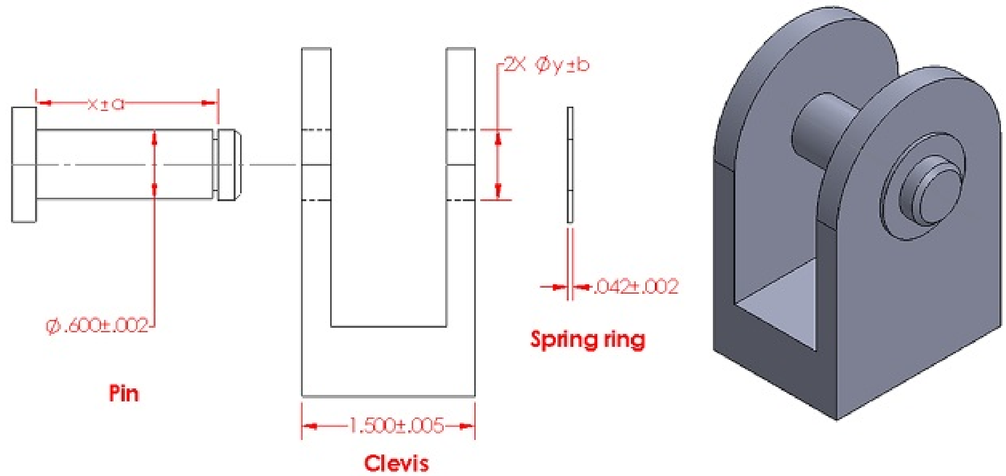


Figure 1. Linkage pivot

For interchangeable assembly processes:

1. Determine the dimension *x* and its tolerance *a*

2. If the pin diameter available in the stock is 0.6 $\pm$0.002 inch and M1 manufacturing process is used to create the clevis holes suggest an appropriate clevis hole diameter y to ensure the minimum clearance between the pin and the hole is E. (Note: use typical tolerance limits b for M1 process, Table 5.2 (or 5.4) in your textbook)

3. Use TolAnalyst^{TM} tool to verify your results from part 1

Notes:

1. $g_{min},\ g_{max}, E,\ \text{and}\ M1$ (b) values are assigned to each student

2. Show your analysis for the parts A and B precisely using both 100 percent and statistical interchangeability methods.

3. Submit the tolerance analysis report for the part C in addition to your linkage pivot assembly and the part files.

The expected learning outcomes from this project are:

- Understanding the relationship between engineering design of product and assembly process using tolerance analysis as a part of the design specification.

- Implementing tolerance analysis for a specific product in x and y-directions using 100% interchangeability and statistical methods.

- Understanding the relationship between the tolerance and the type of manufacturing process used to create different features in the components.

- Understanding and using the TolAnalyst^{TM} simulation tool in SolidWorks to implement tolerance analysis for the assembly and compare the results with the traditional methods.

3.1.2 Project #2 Sand casting of a wolf head

This project is the first in a series of engineering manufacturing processes to create a nutcracker as a final project in this class. The first subproject is designed to provide students with a hands-on experience of the sand casting process of a wolf head shown in Figure 2. It is interesting that our engineering department is one of the few that still offer this real experience with the casting process using an in-school foundry. The students need to use design equations for heat and pouring concepts (Equation 1), and the solidification and cooling process analysis (Equation 2) [14].

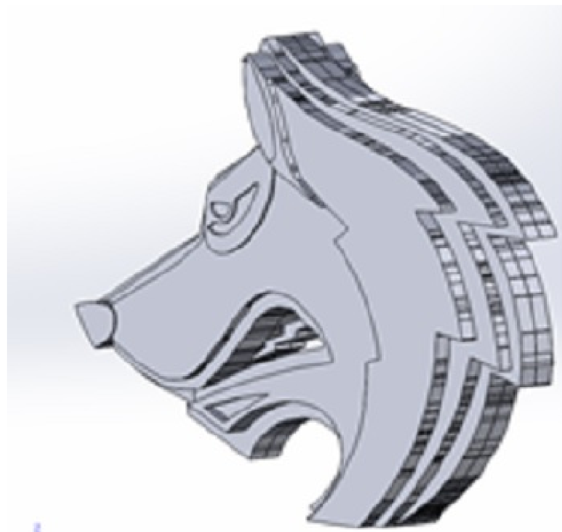


Figure 2. 3D CAD view for the wolf head casting project

The most challenging piece of information that the students need to find is calculating the surface area and the volume of an irregular wolf head part. The students need to use the SolidWorks part file of the wolf head to calculate the surface area and the volume of the casting. Figure 3 shows the casting process in the department's foundry and Figure 4 shows the final casting product.

Heating and Pouring

$$H = \rho V \left[C_s \left(T_m - T_0 \right) + H_f + C_l \left(T_p - T_m \right) \right] \tag{1}$$

- H = total heat required to raise the temperature to the pouring temperature [J],
- ρ = density [g/cm^3],
- C_s= weight specific heat for the solid metal [J/(g ^{o}C)]
- T_m = melting temp. of metal in [^{o}C]
- T_o= starting temperature of metal [^{o}C]
- H_f = heat of fusion [J/g]
- C_l= weight specific heat for the liquid metal[J/(g ^{o}C)]
- Tp = pouring temperature [^{o}C]
- V = volume of metal heated [cm^3]
- Total heat required for pouring (H) = ??

Solidification and Cooling (Chvorinov's rule)

$$T_{TS} = C_m \left(\frac{V}{A} \right)^n \tag{2}$$

- T_{TS} = Total Solidification Time [min]
- V = volume of the casting [cm^3]
- A = surface area of casting [cm^2]
- C_m = mold constant [min/cm^2]
- n = an exponent, usually n=2
- C_m depends on:
  - Mold material
  - Thermal properties of the cast metal
  - Superheat (pouring temperature relative to the melting point of the metal)
- Total solidification time (T_{TS}) = ??

Figure 3. Sand casting process

3.2 Online Quizzes

The instructor developed a new database that includes more than two hundred questions that cover several topics related to the course materials. The Blackboard® assignment tools were used to create and deliver online quizzes. The online quiz is designed to have 5 -10 questions selected randomly for each student linked to the studied topic in the class. These quizzes are designed to improve the critical thinking and understating of the basic concepts and related terminology outside class time. The duration of the quiz is set to be a one-hour continuous session, and the students are allowed to select the exam time within the given time frame for the exam (usually two days).

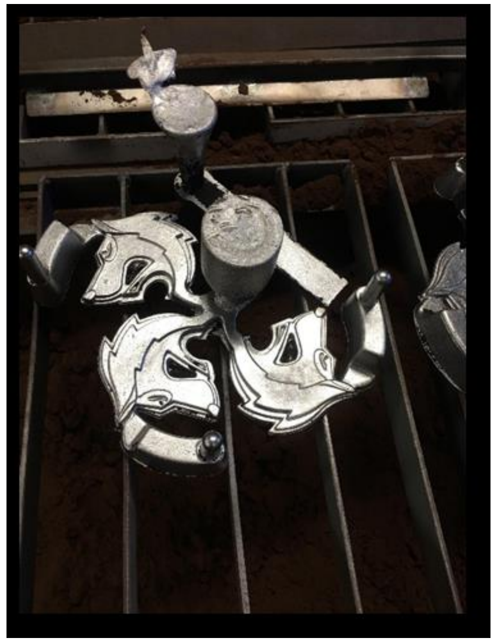


Figure 4. Final product

3.3 Students' Micro-lectures (MLs)

To create passion and interactive course learning environment students' micro-lectures for selected topics were introduced and implemented during the class period.

Each student (or a group of students) prepares a 15-20 min presentation to show his/her/their essential findings related to the selected manufacturing process. The micro-lectures focus on the important features and applications of the selected manufacturing process. Video segments and simulations can be used to enrich students' understanding of that manufacturing process. In addition to the instructor's evaluation, peer evaluations are used to evaluate micro-lectures. Participation in peer evaluations and discussions is necessary for the final assessment of the micro-lectures. It is expected that the micro-lectures demonstrate essential aspects of the manufacturing process as an added value to the information in the lecture notes. The students are urged to start working on their designated topics when the related chapter is started, as listed in the lecture notes. The micro-lectures weight 15% of the final grade. (75% for the presentation and material quality, 25% for peer evaluation). MLs improve student's self-learning skills while helping the students achieve the lifelong learning goal. In addition, this learning approach allows more time to focus on problem-based assignments and mini-projects during class time. The students' micro- lecture topics addressed in this study are listed in Table 1.

4 Results And Discussion

The assessment of the listed outcomes for the new teaching approach is measured directly using the students' evaluation survey (class participation and critical thinking) and students' motivation in students' micro-lectures and projects. The direct evaluation result from class assignments is used to measure a knowledge increase related to the selected course topic. The academic feedback from other faculty members about course implementation strategy and the learning outcomes according to the ABET accreditation criteria is considered in this study as well.

A pre-course survey is prepared to measure students' expectations of the course in general and the instructor's teaching style in particular in addition to some questions that are meant to increase students' awareness of the selected topic (the dimensions and tolerances analysis in the assembly process). The survey results for the class of 24 students showed that about 32% of students hate

Table 1. Micro-lectures topics

#	Topic	#	Topic
1	Selective assembly	**12**	Chemical machining
2	Sand casting process	**13**	Mechanical energy processes
3	Centrifugal casting process	**14**	Electrochemical machining
4	Vertical casting process	**15**	Welding
5	Investment casting process	**16**	Fusion welding
6	Refractory casting process	**17**	Milling
7	Die casting process	**18**	Physical vapor deposition
8	Drilling	**19**	Sheet metalworking
9	Turning and boring	**20**	Solid-state welding
10	Plating	**21**	Grinding, honing, lapping
11	Bulk deformation processes	**22**	Superfinishing polishing, buffing

or dislike the traditional lecture style, 60% do not care, and about 8% love the traditional lecture style.

A post-course survey included more specific questions about the new instructional components in the course (students' micro-lectures, design-based projects, and online quizzes), in addition to knowledge development assessment questions.

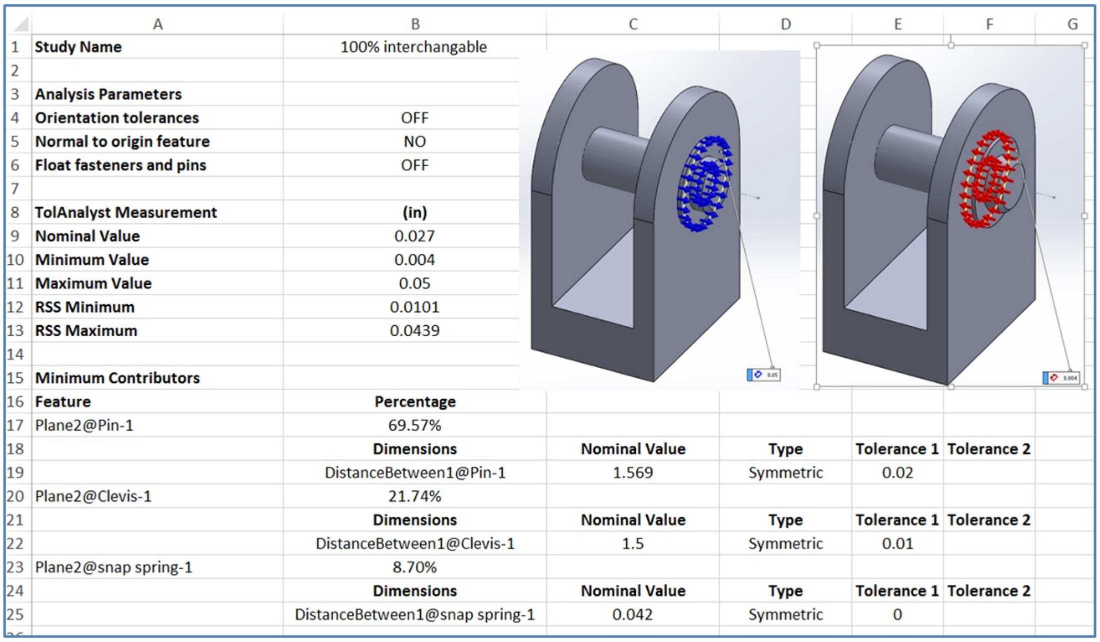
The most interesting result from the post-lecture survey was that 68% of the students answered that they don't like traditional lecture styles. This shows a strong shift in students' opinion about lecturing style from the pre-course survey results, and serves as a strong indicator that adding new teaching and learning components makes the class more enjoyable for the students.

4.1 In-class Simulation Projects and Exercises

The post-course survey shows that 66.66% of students think that the in-class projects and exercises are very useful and 33.33% consider them as useful. When the students were asked for suggestions to improve the in-class projects and exercises, the most important responses were "help understand material better", "watch the videos of the applications before doing the exercises", and "give more time to work on it." Again time is an essential factor in making sure that the pace of the course does not add more pressure on the students. MLs presentations, including short videos and students' performances, help students understand the process (virtually) before starting numerical analysis assignments for the in-class projects.

For the in-class Project #1, 75% of the students were able to solve part A successfully, about 67% of the students were able to solve part B successfully, and about 71% of students used simulation tool (TolAnalyst™) successfully to verify their results from the traditional tolerance analysis of part A (Figure 5). These results aligned with the students' feedback in the post-lecture survey show that 95 % of the students think that the in-class project helped them enrich their understanding of the class topic. Also, more than 62% of students are willing to use the simulation tools in their future work in industry in addition to 35% that may use it. The post-lecture results show that students think that introducing new simulation tools is very beneficial for their future careers as engineers. This is a good outcome when compared with the pre-lecture survey which shows that about 80% of students in this class did not know the simulation tool TolAnalyst™ in SolidWorks. Also, about 80% mentioned that working on the in-class project enriches their understanding of the topics. It is interesting to note that adding simulation tools to the project assignment does not require a considerable additional amount of time from the students. According to the post-lecture survey, about half of the students spent 2 hours and about 27% of students spent 4 hours to learn the TolAnalyst™ tool. Some students struggled with the simulation part of this project due to their lack of basic SolidWorks skills.

For Project #2 Sand Casting, it was interesting to see that most of the students were able to



	A	B	C	D	E	F	G
1	**Study Name**	100% interchangable					
2							
3	**Analysis Parameters**						
4	**Orientation tolerances**	OFF					
5	**Normal to origin feature**	NO					
6	**Float fasteners and pins**	OFF					
7							
8	**TolAnalyst Measurement**	**(in)**					
9	**Nominal Value**	0.027					
10	**Minimum Value**	0.004					
11	**Maximum Value**	0.05					
12	**RSS Minimum**	0.0101					
13	**RSS Maximum**	0.0439					
14							
15	**Minimum Contributors**						
16	**Feature**	**Percentage**					
17	Plane2@Pin-1	69.57%					
18		**Dimensions**	**Nominal Value**	**Type**	**Tolerance 1**	**Tolerance 2**	
19		DistanceBetween1@Pin-1	1.569	Symmetric	0.02		
20	Plane2@Clevis-1	21.74%					
21		**Dimensions**	**Nominal Value**	**Type**	**Tolerance 1**	**Tolerance 2**	
22		DistanceBetween1@Clevis-1	1.5	Symmetric	0.01		
23	Plane2@snap spring-1	8.70%					
24		**Dimensions**	**Nominal Value**	**Type**	**Tolerance 1**	**Tolerance 2**	
25		DistanceBetween1@snap spring-1	0.042	Symmetric	0		

Figure 5. Sample of students work for Project #1 part C.

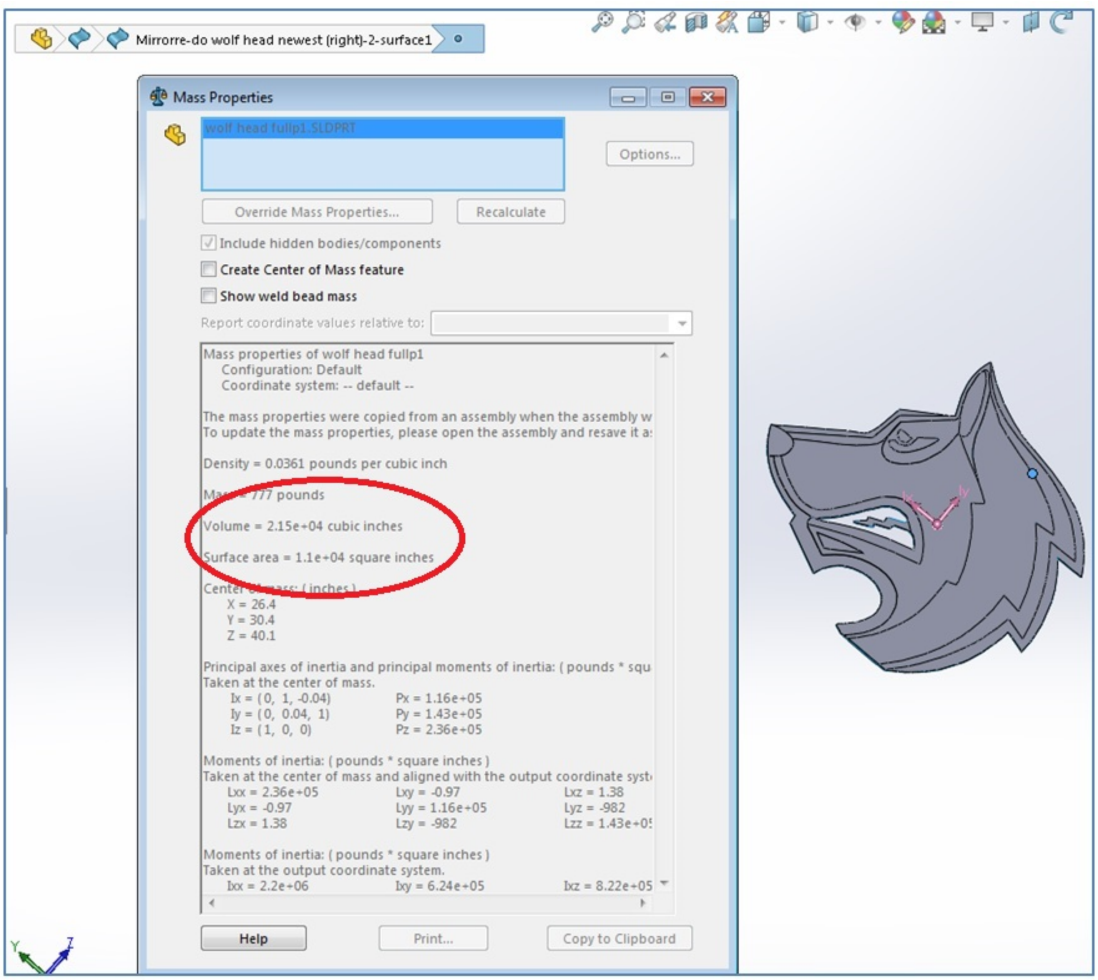


Figure 6. Using Mass properties tool at SolidWorks to find the volume and surface area of the wolf head cast project.

connect the theoretical casting process analysis with the experimental results for the wolf head casting. Also, they were able to determine the required variables and parameters to complete their analysis and to justify some of the sources of errors using a scientific and engineering approach. Besides, the students understood how essential is a single accurate database from the CAD system to complete the design and manufacturing processes accurately. The students need to use mass properties tools in SolidWorks to find the volume and the surface area of the casting as shown in Figure 6. Both parameters are required to calculate the total heat required to raise the temperature to the pouring temperature and the total solidification time as given in Equation 1 and Equation 2.

In general, students' notes and comments listed at the project report show an advancement in their fundamental knowledge gain with respect to the casting process, analytical reasoning, and problem solving using available software/hardware tools to connect the process theory with the real casting process. Some students wrote the following in their reports:

- "*Overall, the experiment was a great learning experience for how casting works in the real world in comparison to the classroom. The equations used in the classroom do not directly transfer to the experiments. Not only did we learn the process but we learned the safety issues and extra steps involved in casting that aren't taught in the classroom. Also, the lab helped us to understand the work that is behind some of the objects we use in everyday life and how difficult it can be to make them perfectly.*"
- "*Overall I think this was a very successful lab and I felt as though I could really connect what I was learning in the class to what we were doing in lab. I felt much more comfortable on the test because of my experiences in the lab. I am a very visual learner and the lab has helped me understand the information much more.*"
- "*After having hands-on experience with sand casting, I have a better understanding of the procedures and process needed to make a casting from a mold.*"

4.2 Online Quizzes

The average quiz score was 92.5%, and all students were able to finish the quiz within the given time frame. The post-course survey results show responses addressing the importance of the online quiz component (not-useful 4.76%, no effect 28.5%, useful 42.85% and very useful 23.8%). The students suggested the following, "helped reinforce vocabulary," "yes, improve our definitions.", and "class quizzes word better." According to the collected results and students' feedback, the majority of the students claimed the online quizzes are useful or very useful. However, it seems that some students still prefer the in-class traditional paper tests.

4.3 Students' Micro-lectures (MLs)

In general, the student's feedback about micro-lectures (MLs) was assessed twice, the first time after week 5 of the semester (only assembly and casting processes topics were covered) and the second survey at the end of the semester (after all topics were covered). In the first survey, about 65% liked and about 12% disliked MLs. In the second survey, 95% of the students consider the MLs to be useful or very useful which shows good consistency about the effectiveness of using MLs to promote students' engagement and improve learning outcomes. In addition, the students were asked to write a single fact they learned from the micro-lectures topic (selective assembly and tolerances analysis). Students' notes and comments about MLs are in general positive and can be summarized as following: Interesting, improve public speaking and presentation skills, change in *class pace and keep students engaged*, increase student to student interactions, and *makes the students really focus on a subject*. Some students disliked the micro lectures for the following reasons: it challenged the students to be expert in this topic, presentation timing, it provides learning opportunity for the student but not for the other students in the class. When the students asked about any suggestion to improve the MLs, the most important responses were: "*let the students work in a group*", "*keep the timing the same*", and "*don't make them too long*". All positive and negative comments show the importance of improving independent and lifelong learning skills through active learning strategies and class participation and discussions. Also, having a more controlled environment will help in maximizing the ML effectiveness.

The students were asked to write a single fact learned from the micro-lectures topic (selective assembly and tolerances analysis). The student's feedback shows increased knowledge and advanced thinking about the subject. For the MLs related to the casting topics, the peer evaluation survey for the casting processes listed in Table 1, shows that more than 80% of the students in the class of 24 students learned or learned much from the micro-lectures. Again, the students were asked to write a fact learned from the MLs topics (sand casting, refractory casting, vertical casting, die casting, investment casting and centrifugal casting). Students' feedback about what they learned from the MLs show strong evidence that student to student interaction is effective and helpful in learning new facts.

Here are some samples of student's answers about what facts they learned from students presentations:

- "*die casting has good dimensional tolerances, centrifugal casting can make giant symmetrical products, vertical casting eliminates trimming.*", "*die casting is cost-effective with high volume demand, especially with metals with low melting points.*",
- "*Investment casting has nothing to do with financial aspects like the name would suggest. It's actually a wax form casting.*",
- "*die casting has good dimensional tolerances, centrifugal casting can make giant symmetrical products, vertical casting eliminates trimming.*",
- "*Centrifugal casting is used in most aircraft, dams, and military products, Die casting is only cost-effective with high volume demand, in vertical casting produce parts with high quality, eliminate trims, quicker molds, reduce cycle time. Refractory anchors are designed to expand to allow the mold to form.*"

1summarizes the effectiveness of different learning activities used in this study (students' presentations (MLs), in-class projects, and the online quizzes) according to the students' post semester survey.

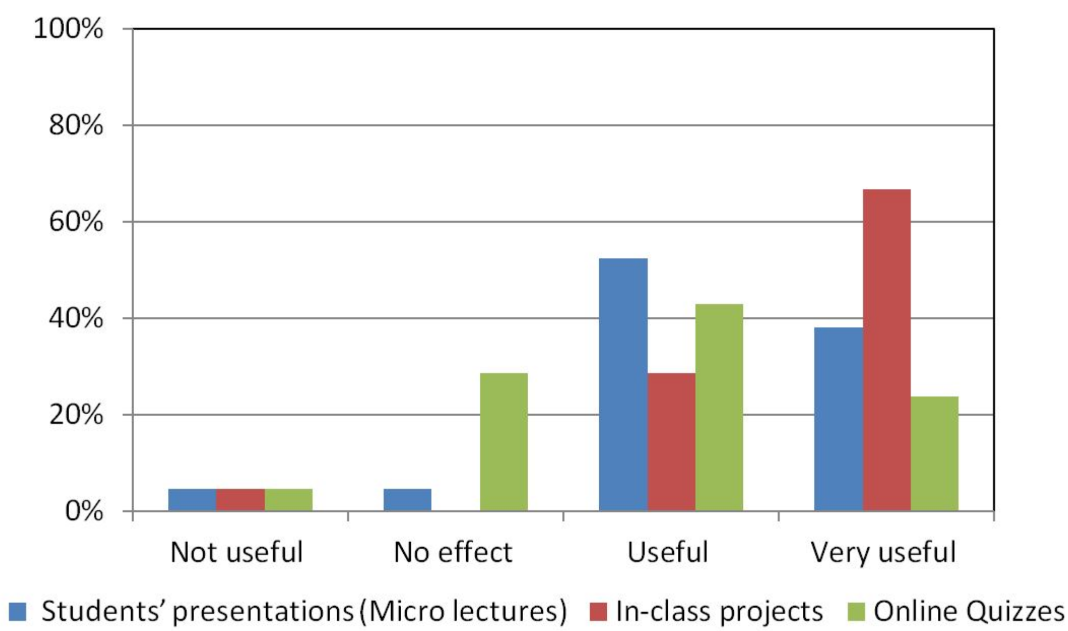


Chart 1: Post-course survey results for the implemented learning activities

5 Conclusion

In this work, a computer-based learning and digital resources (simulation-based projects and online quizzes), in addition to the students' micro-lectures were used to create an active, passive, and constructive learning environment to support the teaching of the Engineering of Manufacturing Processes course. Simulation-based projects were used to support constructive concept-based learning and critical thinking for the students and to integrate simulation analysis with real manufacturing processes in the lab. Online quizzes were used successfully to help students practice and understand the basic concepts and related terminology outside class time. Students' micro-lectures supported the development of lifelong learning skills and created an interactive teaching environment with the instructor and other students. In general, the essential lessons and outcomes from this study can be summarized as follows: First, the simulation-based design projects helped in enriching students' understanding of the studied topic and improved their ability to address the real-world problems and analysis and use their engineering judgment to draw conclusions (ABET Criterion 3. Student Outcomes: 6). Second, introducing simulation tools as a part of the learning environment can be implemented easily and without burdening the students much, especially if they already used the same CAD software as a drafting and design tool. A single CAD database can be used to produce many types of drawings and models used throughout the design and manufacturing processes. Third, online quizzes can be used to help expose students to new terminology and definitions, as well as to learn on their own, based on the available online resources and the textbook. Forth, using students' micro-lectures helped in improving students' life-long learning and communication skills (ABET Criterion 3. Student Outcomes: 3 and 4). Fifth, students' micro-lectures increased students' learning outcomes by making the class more interactive, and eventually, can be used to expose the students to the manufacturing process concepts and methods that can help them solve numerically-based exercises and problems.

The suggested teaching strategy can work effectively with small classes and maybe mid-sized classes if the instructor (s) can provide adequate resources. For future work, the authors are planning to introduce more simulation-based projects in the curriculum like machining simulation and cost analysis of casting.

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