AC 2011-751: GOING WITH THE FLOW IN A SERVICE LEARNING PROJECT

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Abstract

Accounting for the flow of a fluid is important in any design. In the engineering of products that are subjected to a fluid environment, the design cycle often begins with a 3D computer model rendition. Computer generated models can then be exposed to a simulated fluid environment through Computational Fluid Dynamics (CFD). The model in turn may be brought to life through a 3D printer and subsequently used as a subscale test article. Through a process such as this, the initial design can be optimized at a significantly reduced developmental cost.

Junior-level mechanical engineering (ME) students were exposed to the concepts associated with the design process using commonly available technology in a fluid mechanics course. The 3D computer model was created using a modeling software package which has an embedded CFD flow simulation analysis tool. The mold for the physical model was fabricated with a 3D printer using ABS plastic and the subscale test article was made from a silicone elastomer. The subscale test was conducted using Particle Image Velocimetry (PIV) techniques. The ME students participated in all aspects of this process.

In order to help the ME students better understand the concepts of the fluid mechanics involved, a service learning component was incorporated into the project. Service learning has been shown to be a valuable approach in authenticating classroom learning experiences. Student teams from the class traveled to local middle and high schools to engage the younger students in the somewhat abstract flow concepts associated with fluid mechanics using common examples. The ME students explained flow concepts such as streamlines, separation, drag, and lift and showed examples of the various phenomena using computational and physical models. Groups of middle and high school students were tasked to hand-draw a common shape and predict the associated streamline pattern of the flow around the shape. The ME students then manufactured this shape, analyzed the flow around the object and subsequently demonstrated the results to the students during a return visit.

This paper describes the feasibility of introducing design concepts in fluid mechanics through common technology available in a university setting. The ME students studied the conceptual theory of flow in the classroom and utilized service learning as a way to apply what they learned to lower-level students in an effort to better understand the concepts themselves. An assessment is provided to help gauge the value of the service learning component of the course.

I. Introduction

Fluid mechanics is often seen as a difficult core subject for engineering students. The difficulty stems from the necessity to visualize complex flow patterns and fluid behavior modeled by high level mathematics. In textbooks and classroom lectures fluid mechanics is often treated as abstract, mathematical and conceptual. Innovative teaching methods that will enhance student learning in this area are being explored within the curriculum of the mechanical engineering (ME) program offered at Mesa State College (MSC) located in Grand Junction, Colorado as part of an engineering partnership between the college and the University of Colorado (CU) at Boulder (Boulder, Colorado).

This is the third year of the engineering partnership between MSC and CU-Boulder. Students reside all four years at MSC, the latter two years taking CU-Boulder mechanical engineering courses taught by CU-Boulder faculty. The leading student cohort numbers 10 and are now undertaking their junior year. The small class size inherent in the program allow faculty to experiment with various teaching methods, making it a proving ground for teaching innovations that can be transferred back to the home campus in Boulder. One such innovation, a service learning component, was introduced into the course work of a core junior-level ME course entitled Fluid Mechanics.

The service learning approach will authenticate and reinforce the classroom learning experiences by improving students' understanding and appreciation of flow concepts such as streamlines, separation, drag and lift. It will also help students develop an attitude toward outreach, making it a highly effective character education program. Having the students go into middle and high school classrooms to explain the somewhat abstract flow concepts to K-12 students using real-life examples in a real-world context will benefit not only the ME students but also the K-12 students. Home campus students will also benefit from having the approach tried, reviewed and refined before it is implemented in their program.

In order to understand the full extent of this service learning class project, a description of the various technologies that the ME students used are presented.

II. Technology

Solid Modeling and Computational Fluid Dynamics (CFD) Components -

SolidWorks, a parasolid-based solid modeler that utilizes a parametric feature-based approach to create models and assemblies, is the 3D software package used for the entry-level Computer Aided Design (CAD) course in the ME Partnership Program. Students take the CAD course in their freshman year. The computational fluid dynamics (CFD) application in SolidWorks is called FloXpress. FloXpress is simple to use and gives a representation of flow characteristics around solid objects. However, students are not formally taught to use the CFD application in the CAD course. Experience has demonstrated that the junior-level ME students pick up the concepts of using the CFD module easily.

CFD is sometimes used in undergraduate fluids courses to expose the students to the power of computational methods to solve complex fluid flow problems. Markers, within the CFD program, represent flow paths and varying colors are used to illustrate velocities. The movements of the particle-like markers demonstrate a rough plot of the flow direction and velocity. In areas of high velocity, the particles are red or orange. Where the flow is moving slowly or where there is recirculation, the particles are blue. Medium velocities are assigned the colors of green and yellow.

Since the design process in engineering is highly iterative, students discover that CFD can readily be used for design optimization. Students find that using FloXpress and SolidWorks software together can efficiently optimize products in which fluid flow is an important design parameter.

Particle Image Velocimetry Component -

Particle Image Velocimetry (PIV) is a unique laser based state of the art technology in fluid flow research that enables visual and quantitative analysis of the flow field. Here, flow field refers to the velocity of fluid particles as a function of position and time. PIV is widely used in research and industry ranging from aircraft aerodynamics to improving heart implant devices. In fact, PIV was one method used to analyze the amount of oil leaking into the Gulf of Mexico from the April 2010 BP Deepwater Oil Spill.

Since PIV is an optical method of visualization, it is ideally suited to the highly visual subject of teaching fluid mechanics. The device used in the fluid mechanics course is manufactured by Interactive Flow Studies, LLC, called Educational Particle Image Velocimetry[1] (ePIV), as shown in Figure 1.

Figure 1. Educational Particle Image Velocimetry (ePIV) device.

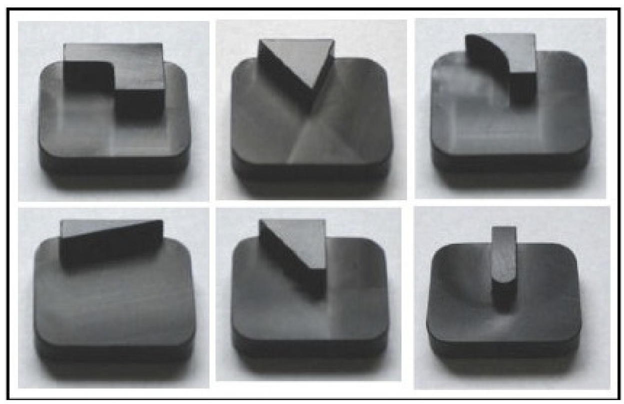

Figure 2. Typical inserts used in the ePIV. Vendor supplied shapes.

The ePIV device utilizes fluid seeding techniques for flow visualization. A closed loop water system is seeded with neutrally buoyant particles with diameters ranging between 10 and 50 micrometers. The seeded water is pumped through a Plexiglas chamber and interacts with the model of the object of study. A laser illuminates the particles in the water, which allows them to become visible. A built-in digital camera is used for capturing still images and videos for use in flow studies and presentations. Models for the ePIV device are typically referred to as flow inserts. A collection of vendor supplied flow inserts made from aluminum and painted black are shown in Figure 2. Inserts can also be made from a clear material so that light from the laser can

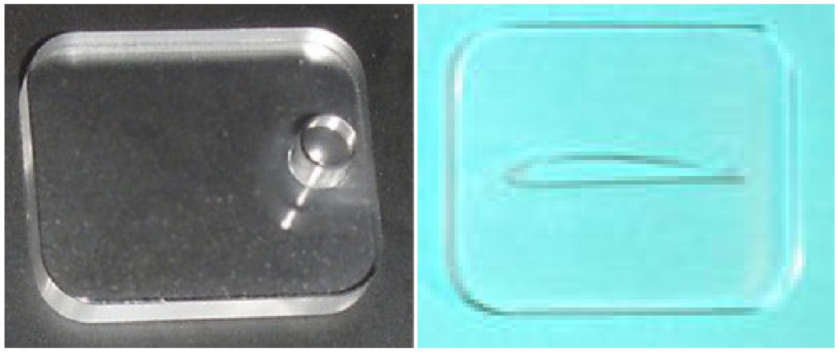

Figure 3. Typical silicone insertsused in the ePIV. Made from 3D printer mold by partnership students. (R) airfoil shape, (L) cylindrical shape.

transmit through and illuminate the entire viewing area of the camera. See examples of a circular cylinder and an airfoil flow insert made from silicone in Figure 3.

3D Printer Component -

The use of a 3D printing machine, a variation of rapid prototyping, has become commonplace in technology classes from high school through university in recent years. 3D printing is a form of additive manufacturing where a three dimensional object is created by laying down successive layers of material. Access to 3D printing at the university allows students the ability to print models that they design in SolidWorks directly and easily. The particular machine used in the engineering partnership program is the Dimension SST 1200es 3D Printing System with a build envelop of 10”x10”x12”. The Dimension SST produces ABS models with “wash away” support structure. The 3D printer was used to make a negative space mold of various shapes that were designed in SolidWorks.

Silicone Elastomer Component –

The molds, fabricated using the 3D printer, were filled with a clear silicone. Sylgard 184 silicone elastomer is a two-part liquid 10:1 ratio that when cured becomes a flexible, transparent elastomer. When completely set, the elastomer resembles rubber and is characterized by having the ability to resume its shape after being greatly deformed.

III. Discussion of Project

Service Learning Component -

An important aspect of the project was for the ME students to participate in service learning. The task was to visit local schools and give a presentation on fluid mechanics and the engineering design process, emphasizing flow separation, drag and lift. Faculty contacted local schools to identify classes that would benefit from the teaching provided by ME students as part of the project. Three classes were identified, two middle school science classes and one high school physics class. Three teams of ME students were then established and allocated one of the school classes. The ME students gave a brief presentation on engineering in general, aspects of mechanical engineering, and information specific to fluid mechanics. They then described 3D modeling, CFD, PIV, and the design process. The teams demonstrated the capability of the ePIV by showing representative flow profiles around typical protuberances. They discussed real-life situations where streamlines and separation are observed and then related the phenomenon to the resulting drag and lift consequences.

The middle and high school students were then asked to choose a shape that they would like to investigate and to make predictions for streamlines and particle trajectories around the shape. Areas of drag and relative fluid velocities were also predicted. Representative middle school classroom drawings are shown in Figure 4.

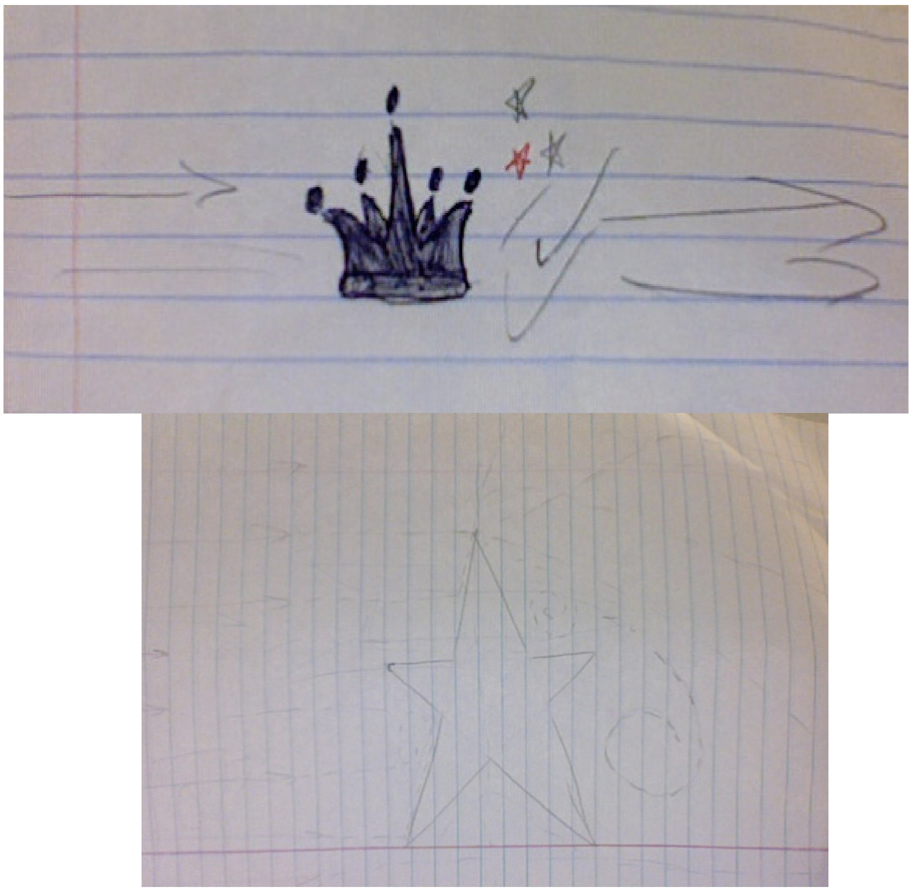

Figure 4. Pictures drawn by middle school students with flow predictions, crown (top) and star (bottom).

The ME student teams took the middle and high school student designs back to the lab and designed 3D molds with the SolidWorks program, as shown in Figure 5 for the “crown” shape. A physical mold of the model was made with the 3D printer followed by actual flow inserts for the ePIV from the silicon elastomer, Sylgard 184 (both the mold and the flow insert are shown in Figure 6 for the star, pumpkin and crown shapes). The 3D models developed in SolidWorks were analyzed with the FloXpress CFD tool. Representative results are shown in Figure 7 for the “star” shape. Pictures and videos of the CFD and physical model were made and incorporated into the follow-up presentation that the ME students gave to the middle and high school classrooms.

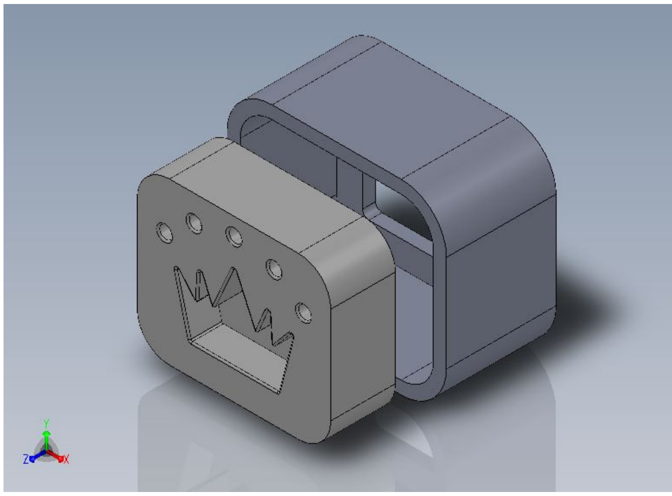

Figure 5. Crown shaped mold made with the CAD program SolidWorks by partnership students.

Figure 6. Molds of the Star, Pumpkin and Crown shapes made with the 3D printer (below). Silicone inserts of those shapes, respectively (above).

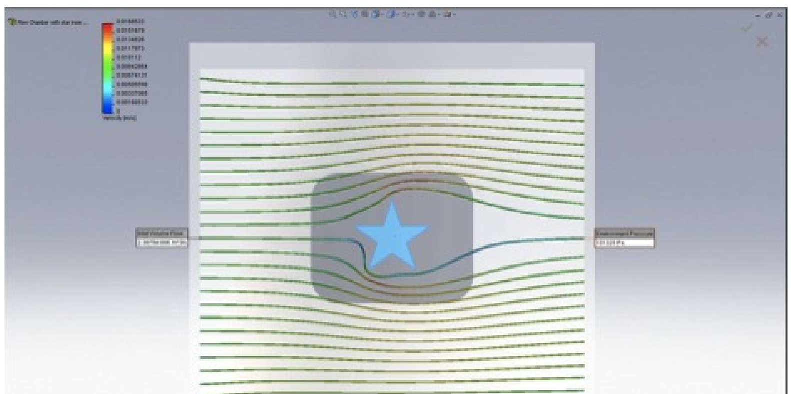

Figure 7. SolidWorks and FloXpress CFD representation of the Star shaped object.

A summary of the tasks that the ME students had to complete in order to finish the service learning portion of the project:

1. Conduct an introductory presentation to the middle and high school students,
2. Acquire the middle and high school student's shapes and predictions (Figure 4),
3. Create a 3D SolidWorks model of the shapes (Figure 5),
4. Analyze the shapes in a simulated flow environment using the FloXpress CFD application (Figure 7),
5. Create a mold for the shape using the 3D printer (Figure 6),
6. Manufacture a flow insert of the shape using silicone elastomer (Figure 6),
7. Test the shape in the ePIV (Figure 8),
8. Produce videos of the resulting flow patterns,
9. Conduct a return visit to the middle and high school class to present results.

Figure 8. Star shaped silicone flow insert inside the water chamber within the ePIV.

The ME student team returned to the middle and high school classrooms with follow-up presentations. They showed the SolidWorks renderings, the molds, the flow inserts, and the results from the CFD simulation. Videos of the inserts from the ePIV were shown and compared to the results found using CFD. The ME students discussed each classroom group's design and compared the students' predictions with the actual results. A focused emphasis was placed on the technology used in the lead-up to the final design. Being able to test a shape computationally, then using a physical model before actually manufacturing the final product was pointed out repeatedly. All the middle and high school students understood the processes used by the ME student team and why they are important to engineering. The ME student team succeeded in gaining the students' interest by introducing them to advanced engineering processes early in their education.

IV. Service Learning Assessment

Service learning has been reported to be of value in engineering education from "1st-Year Experiences" to the program "Engineers Without Borders" [2, 3, 4, 5]. One way to evaluate the value of the service learning aspect of this project was to use Concept Inventories (CI) for the fluid mechanics course. CIs establish a common base for student knowledge in fluid concepts and provide an instrument that can be used to evaluate the degree to which students have mastered the concepts. A possible outcome of the inventory results in the actual ME program could be modification of the fluid course content. The CIs were already in place as a way to measure student learning for accreditation. A CI inventory exam is given the first day of class (pre-test) and the same exam is given the last day of class (post-test). A percent gain can then be calculated.

The CI given in the ME Fluid Mechanics course consisted of 30 questions. In general the CI questions could be broken down into six major generic categories, pressure, Bernoulli's principle, velocity profiles, momentum, viscosity, and drag/lift. The breakdown of which fluid category pertained to which CI question is given in Table 1. The specific questions in the CI were hard to group into specific categories that related directly to the service learning project. This is a problem that future studies could address.

Table 1. Correlation of Fluid Category to the Concept Inventory Question

Fluid Category	Problem Number
Pressure	5, 7, 8, 9, 10, 12, 16, 28
Bernoulli's Principle	1, 2, 11, 15, 20, 21, 25, 29
Velocity Profiles	3, 14, 19, 22
Momentum	4, 23
Viscosity	6, 13, 17, 24, 30
Drag/Lift	26, 27
Question was determined to be invalid	18

The categories that were most relevant to the ME student learning associated with the service learning project were Bernoulli's principle and velocity profiles. Twelve questions pertained to these two fluid categories, as indicated in Table 1. The percent gains, that is, the difference between the post-test and pre-test percentage of students answering correctly on a given question, for all 30 questions are given in Figure 9. A mean and one standard deviation from the mean were determined to be 14 and 36% gain, respectively.

Figure 9. Fluid Mechanics Concept Inventories, % Gains

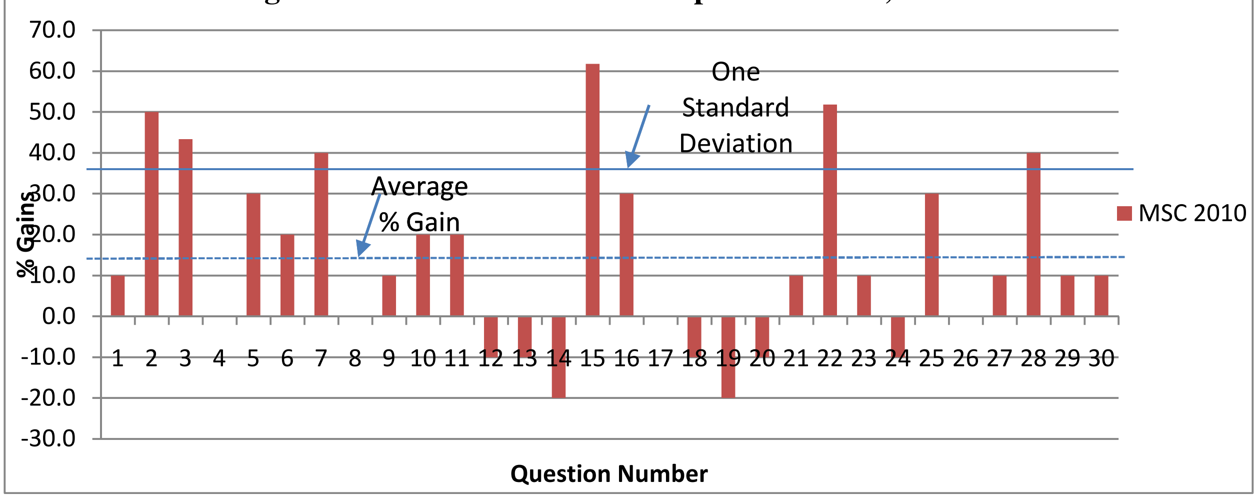

Figure 9 shows that there were 6 questions where the students achieved a higher % gain than one standard deviation from the mean (questions 2, 3, 7, 15, 22 and 28). Of those 6 questions, 4 of them were from the Bernoulli principle and velocity profile categories. One can conclude that the service learning project did enhance student learning in the ME fluid mechanics course to some extent.

V. Concluding Remarks

It has been shown that introducing design concepts in a junior-level fluid mechanics course through the use of common technology is feasible. Student learning was enhanced through incorporating a service learning component. University students conducted visits to two middle school and one high school class rooms and brought various shapes of interest to the school children back to the laboratory. A 3D computer model of the shapes was created using the SolidWorks software package. A SolidWorks embedded CFD flow analysis tool was used to simulate the flow profiles around the shapes. A mold for physical models of the various shapes was fabricated with a 3D printer using ABS plastic and a subscale test article of each shape was made from a silicone elastomer. Subscale tests were conducted using Particle Image Velocimetry techniques. The university students showed the school children the results of their project on a return trip to the schools.

In order to quantify the enhanced student learning acquired in this project, questions from a pre and post fluid mechanics Concept Inventory exam were asked of the ME students. Results were analyzed and it was shown that students scored relatively higher in questions that were directly related to the service learning project compared to other questions. However, the small student sample class size (n = 10) and the fact that the Concept Inventory questions were not necessarily specific to the service learning component (most addressed other learning objectives) could provide fodder for criticism.

VI. Bibliography

1. Okcay, M. and Oztekin, U., Educational Particle Image Velocimetry Interactive Experiment Suites, Proceedings of the 2008 American Society for Engineering Education Annual Conference & Exposition, Session 3426, June 2008.

2. Engineering Projects in Community Service (EPICS) National Program http://epicsnational.ecn.purdue.edu/public/program/national_program.php.

3. Penn Engineering: Undergraduate Student Service Learning Activitieshttp://www.seas.upenn.edu/community/index.php.

4. Tsang, E., Newman, E.J. (1998). *Service-Learning's effect on engineering students and K-12 teacher partnership in an `Introduction to Mechanical Engineering' course*. Proceedings - Frontiers in Education Conference, Institute of Electrical and Electronics Engineers, Inc., v 3, p 1279-1282.

5. Engineers Without Borders, http://www.ewb-usa.org/.