Aeronautical Engineering in a Multimedia Classroom; Developing a Physical Feel for Aerodynamic Models.

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ABSTRACT

The primary goals for the integration of computer simulation and multimedia into the engineering classroom are to improve students' understanding of the natural world and to increase their enthusiasm and vision for the possibilities of engineering. Computer visualization and multimedia presentations can motivate and empower students to explore and exploit mathematical models of the natural world, while developing their engineering intuition and understanding of important physical relationships.

Junior level engineering students in an introductory aerodynamics course at the U.S. Military Academy were exposed to diverse computer simulations and multimedia presentations in West Point's Advanced Technology Classroom Laboratory. Through the use of interactive software in an active learning environment, students were able to easily consider various combinations of aerodynamic parameters, develop an intuitive feel for realistic values and study the impact of varying different engineering parameters. Appropriate emphasis was placed on the use of fundamental conservation laws and mathematical models so that the students were better able to learn engineering with the assistance of mathematics, not despite the mathematics. This class helped the students develop a solid engineering foundation based on physical understanding, that supported them in more advanced engineering courses.

INTRODUCTION

Understanding the net forces acting on an airfoil has never been difficult for the student. The concepts of lift, drag, weight, and thrust are generally easy for the student to understand and to "picture" in his or her mind. Unfortunately, this only helps the student in experimental aerodynamics. In the world of theoretical aerodynamics, the student must be able to develop and use mathematical flow models that will produce the forces and moments acting on an airfoil. While relatively simple potential flow models for aerodynamics have been around for a long time, it remains a daunting conceptual leap for students to visualize these mathematical models and their relationship to the physical world. This difficulty often leaves students confused about the implementation of these aerodynamic models to understand the flow around any body, and unsure of their ability to perform the long and tedious calculations and obtain a realistic result.

At West Point, we exposed students to the visual aspects of potential theory first and then worked with them to perform the mathematical calculations necessary to accurately model flow about an airfoil and the associated forces acting on that airfoil. During a recent semester instructors in the Department of Civil & Mechanical Engineering led students through this visualization process using a multi-media classroom which allowed the students to develop and solve important mathematical relationships using MathCad software. One of the most important parts of the process is the ability to readily change key parameters in potential theory and observe the results. Computer simulations developed in MATLAB along with active learning techniques allowed the students to better understand the fundamentals of potential theory and how it can accurately predict aerodynamics forces in many situations.

Why Computer Simulation and Multimedia in the Engineering Classroom?

A question frequently contemplated when teaching engineering is: "Which do I teach first the physical processes involved in the problem or the mathematical model?" In the past, many teachers have answered that they would rather start with the fundamental laws of physics and derive the mathematical model in accordance with reasonable assumptions. While this ensures that the student is well grounded in the natural conservation laws and appropriate constitutive relationships, it generally does little to enhance the student's understanding of what physically is happening. Consequently, when students apply the equations to the solution of a particular problem, they lack the ability to interpret the solution or comment on its validity. They do not know for sure whether the answer "makes sense". They do not soon develop the "engineering intuition" which allows engineers to recognize 'reasonable' values for the governing parameters of a model. At the undergraduate level developing a student's "Engineering Intuition" should be a primary goal of any engineering discipline. This "common sense" can only be developed if the student understands what is physically happening. We want to get students away from getting answers to problems simply by finding an equation with the right variables in it.

The most important advancement that computers can contribute to education is the ability to visualize mathematical models of the physical world. A physical understanding of the world is acquired from the recognition of the patterns in nature. These patterns are best seen visually and are most recognizable when the parameters of a problem are varied and the resulting images observed. While this approach works well in experimental aerodynamics, it is normally inadequate to teach theoretical aerodynamics with the heavy reliance on the complex calculations not easily repeated.

Because of the difficulty to effectively link the mathematical models and the physical world, students often never see the correlation between them. The key in engineering is to develop the "bridge" or link between the mathematical model and the physical world so that the student can use the mathematical model to effectively predict the results of alternative designs. This bridge helps students to see the patterns generated in problem solving. Without recognizing these patterns, the students will never understand the full significance of the mathematical model. The ultimate goal is to develop in students the ability to construct simple models of the physical world and understand the limits of the model to represent the physical world. If students can do this, they can solve the many diverse real problems that will be presented to them as they attempt to become engineering designers.

An Experiment in an Introductory Aerodynamics Course

In a recent introductory aerodynamics course which emphasized both experimental and mathematical modeling of airfoils and wing sections, students were encouraged to construct the bridge themselves between the mathematical model and the physical reality. Using both mathematical assistant software (MathCad) and self-paced computer exercises, students were able to experiment with the mathematical equations of the model and discover for themselves the patterns they contained. The students used the math software to modify the relationships and vary the model parameters. They could then visually observe the effects of these modifications without becoming bogged down in the drudgery of numerous calculations and the inevitable errors that result. They could actually see the forest because they were not focused on the individual trees.

During the spring semester of 1995, the Introduction to Aerodynamics course was taught in West Point's Advanced Technology Classroom Laboratory (ATCL). This classroom laboratory was designed to allow instructors to experiment with computer technology and diverse teaching techniques and observe the effect on student learning. The classroom placed a networked computer workstation in front of each student while the instructor had access to a similar computer as well as a CD ROM, a video player and a copy camera. The copy camera allowed the instructor to display the textbook on a screen for students to follow a derivation in the book and make notes in their books. This device proved to be very effective at improving instructor communication.

The goals of teaching this course in ATCL in addition to the normal course learning objectives, were:

1) Improve student understanding of the fundamental laws governing aerodynamics.

2) Develop the "engineering intuition' within each student so that he/she could develop problem formulation skills as well as correctly interpret their solution to the problem.

3) Enhance student enthusiasm for aerodynamics so that he/she will be individually motivated to learn more about aeronautical engineering in particular and the world in general.

4) Learn about the use of technology in undergraduate engineering education.

In addition to the increased use of classroom technology to achieve these objectives, we increased student involvement in the classroom through active learning techniques. These techniques focused on student exploration of the mathematical models through in-class self-paced exercises as well as out-of-class computer exercises. These computer exercises were designed to allow the students to effortlessly change different parameters within the model and immediately see the impact of their change through graphical output. The instructor main purpose was to engage students in higher level discussion of the results of each individual student's exploration. Students were free to move to the various workstations to see what their classmates had discovered. This created an atmosphere of learning for all and encourage aggressive exploration by all students since they got to choose their own path.

The measurement of these goals proved a much bigger challenge than originally assumed. It was not possible to compare scores on graded exercises between different semesters because both the course and the graded exams were so fundamentally different. Students were given regular comment and timesheets in which they were permitted to frankly comment on the course and the instruction. These surveys were strictly anonymous and the students were serious about their role in improving the course. They especially enjoyed the freedom to explore in the course and the free flowing discussions with the instructor.

The third goal addressed a problem faced by all engineering instructors. "How do I get the student to prepare for a lesson in advance so that we can conduct a meaningful discussion of the important points of the lesson, rather than simply repeating the lesson from the text on the blackboard for the students. This goal was accomplished through the use of frequent in-class quizzes and feedback sheets. It was important that the students understood their responsibility for all material in the syllabus not just the content covered in the classroom. The quizzes and feedback sheets required only 5 minutes from each class period and while not universally accepted at the beginning of the semester, they were rated as one of the top two greatest aids to their learning by 80% of the students in the course.

One of the most confusing and conceptually difficult aerodynamic relationships for beginning students is the connection between the mathematical concept of circulation and the physical lift force of an airfoil. Lift is modeled mathematically by the Kutta-Joukowski theorem as:

$$Lift = \rho V \Gamma$$

where: ρ is local density
V is local Velocity
Γ is circulation

While this seems like a straight forward equation, the definition of circulation is conceptually hard for undergraduate engineering students to understand. For this discussion, the goal was to aid students understanding of circulation and its relationship to both lift on an airfoil and to potential theory. Circulation is nothing more than a mathematical model which relates lift and vorticity. Vorticity is nothing more than the curl of the velocity vector and it seems we are back to the Kutta-Joukowski theorem. This concept was visualized by the use of a MATLAB developed program to visualize potential flow and permit the students to "play" with basic potential theory building blocks. By changing the parameters of the problem they could calculate the circulation they produced and consequently how much lift was predicted using the Kutta-Joukowski theorem. The instructor was then able to discuss the existence of circulation in physical world and what really causes lift on an airfoil.

Conclusions

We have only begun to explore the proper role of technology in undergraduate engineering education. The need for a model of student learning has become clear. With such a model, we can begin to understand how students learn in the same manner that we attempt to understand aerodynamics. The following are the preliminary conclusions from this academic experiment.

- Visualization is an essential aid to recognizing patterns that lead to understanding.
- Computer technology has a great ability to take away the drudgery of calculations and add insight.
- MathCad is an excellent mathematical assistant.
- The history of aerodynamics is a valuable asset for motivating students.
- It is difficult to measure improvements in learning that result from the use of technology in learning. This is especially true when evaluations based on old teaching techniques are used. New metrics need to be developed.
- Be careful that technology in education does not devolve into a computer game mentality.

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