

Integrating CAD into an Already Packed Curriculum: Is Another Class Necessary?

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Abstract

ABET criteria and industrial demands for both breadth and depth can create overloaded engineering curricula. One possible option for alleviating some of the overload is to eliminate the stand-alone CAD class by incorporating CAD into a low level design course. A case for CAD integration into existing courses is presented. Three options we have recently used for teaching CAD include: 2-D drawings integrated into a 200 level design course; 3-D solid modeling in a 300 level course devoted exclusively to CAD; and, 3-D solid modeling integrated into a 200 level design course. Assessment metrics developed are based on learning styles (the Kolb model, scaffolding, and inductive/deductive), content (% reduction/increase in topic coverage), and context (stand-alone tools vs. industrial design iteration). Historical feedback from both students and professors provides additional assessment data. Professor feedback includes effect of CAD pedagogy on follow-on course student preparation and performance. A solution is suggested which not only fits into an existing program, but also integrates the CAD "tool" naturally into the designer's toolbox. It is shown that CAD inclusion can be extensive and extremely complimentary without sacrificing instructor time, program requirements, or critical topic coverage.

1.0 Introduction

Packing Engineering curricula with more and more courses is one way to satisfy the demands of ABET¹³ as well as incorporate new technology to keep pace with industry advances^{11,16,22}. Certainly, the "Just-In-Time" approach has been used – new engineers learning software packages "independently" or through training classes after graduation^{16,22}. This approach has proven less than desirable for students as well as employers – taking extra time and money away from production, and, many times learning tools out of the useful integration of knowledge context¹⁰. In particular, different options for including CAD in the curriculum have been adopted^{2,3,4,5,19,23,25}. This presents a dilemma placed in the domain of undergraduate curricula. In the specific arena of Computer Aided Design (CAD), the United States Air Force Academy (USAFA) has employed 3 experiences converging on a preferred solution.

2.0 CAD Integration Experiences

The Department of Engineering Mechanics at USAFA has incorporated CAD into the curriculum in various ways over the past 10 years. Most significant in these strategies include: the integration of 2-D CAD into a sophomore level Engineering Design course (EM 290) via 3

lessons; the integration of 3-D solid modeling CAD into a junior level CAD/Geometric Dimensioning & Tolerancing (GD&T) course (EM 495); and, the integration of 3-D solid modeling CAD into a sophomore level Engineering Design course (ME 290) in 15 lessons.

2.1 EM 290: 2-D “Short Course” in Engineering Design

2-D CAD was integrated into Engineering Design to present, among other things, the advantages and disadvantages of CAD in the design process. The importance of engineering drawing accuracy was emphasized and simple drawings were required of the students using, in this case, Design View™.

Since this was merely an overview of drafting and a simple software tutorial, the students gained little appreciation of the usefulness of CAD in the design process. The superficial coverage of the software also left students with minimal ability to take their learning to other courses and beyond. Obviously, this was better than nothing, but lacked the depth and knowledge required of a graduating engineer.

2.2 EM 495: 3-D “Full Course” in Computer Aided Design and GD&T

Because of the increased use of solid-modeling software packages in industry and because educational pricing made purchasing feasible, a stand-alone CAD/GD&T course using Pro/ENGINEER™ was developed to meet industrial as well as ABET criterion. The steep learning curve of 3-D solid-modelers stipulated a move from the 3 lessons devoted to Engineering Design to a full course incorporating many aspects of the software tool.

Students were required to learn the software, from drafting to assembly creation, during the first half of the semester and then apply the software to an original or re-design problem during the second half of the semester. Theory of GD&T was incorporated to perfect engineering drawings and interfacing software was incorporated for dynamic analysis, stress analysis, and Computer Aided Manufacturing (CAM) to complete the “paperless shop” of an engineering professional ¹⁵.

This course brought tremendously positive reviews from students and professors alike because it was not merely a superficial topic coverage, but an in-depth study and application of a powerful industrial standard as well as a contextual application in the design genre. However, the course did add another class to an already packed curriculum.

2.3 ME 290: 3-D “Integrated Course” in Engineering Design

The desire to ease the curriculum at USAFA, especially for the 160-semester hour Mechanical Engineers, was the driving force to move CAD back into the sophomore level design course. A downgrade in software performance was not acceptable and an expansion of the course was objectionable. This dilemma birthed a compromise: award an additional credit hour (4 vs. 3) by adding a 2nd hour laboratory to this already time intensive course and teach only the 3-D solid-modeling software (neglecting GD&T) to include drafting and assembly creation. The context of the original course could then be used to develop software and design skills concurrently. Due to the nature of the course – redesign the first half of the semester followed by original design the

second half²⁴ -- the software would be applied twice in each venue over the course of the entire semester.

To capitalize on previous student experience and decrease the learning curve of 3-D solid modeling, a switch was made to AutoCAD's Mechanical Desktop™. This icon-based software with built-in helps and Microsoft™ interfacing aided the consolidation of the course as well¹⁶.

The laboratory hour of the first 15 lessons was devoted to CAD and the following 27 lab hours devoted to coursework and prototype development. The same format was used as the EM 495 course: a brief introduction to the material followed by a step-by-step tutorial with projects for each topic²⁰. In-class and take-home application quizzes were given to ensure internalization and not merely an ability to follow directions. Students worked in teams of two which fostered dialogue and alleviated 90% of questions while professors roamed the lab answering questions and posing new scenarios.

3.0 Assessment

In order to determine which course of study was most effective, several assessment metrics including student feedback, professor feedback, learning theory data, and topical coverage were employed.

3.1 Assessment -- Student Feedback

Simply based on student feedback, both verbal and through course evaluations, the EM 290 2-D "Short Course" was by far, the lowest ranked methodology. The 3-D "Full Course" was a very positive experience, yet took the place of other important majors courses. The final iteration of incorporating 3-D CAD into ME 290 was met with overwhelming success. Not only did the students feel they now had a tool they could take with them to follow-on courses as well as industry, they knew how to apply it in the direct context of their program of study.

3.2 Assessment -- Professor Feedback

Professor feedback concerning the 3 CAD options appears to be unanimously in favor of the 3-D "Integrated Course" option. However, various professors acknowledge that this was by no means a perfect solution. The loss of content when compared to the 3-D "Full Course" was seen as a major drawback. Also, the added time requirements of the 3-D "Integrated Course", when compared to the 2-D "Short Course", were considerable.

3.3 Assessment -- Scaffolding & Inductive/Deductive Learning Theory

The term "scaffolding" is used to denote a group of learning theories which are based on the idea that new knowledge is acquired by linking it to previous experience¹². This idea has been used to enhance design education, as well as engineering education in general, in a variety of contexts^{21,1,27}. In this sense, new knowledge is best learned in an environment where it can be easily seen and/or applied in the context of previously learned concepts. In this light, either of the two CAD options where the CAD content is taught as part of the design course would appear

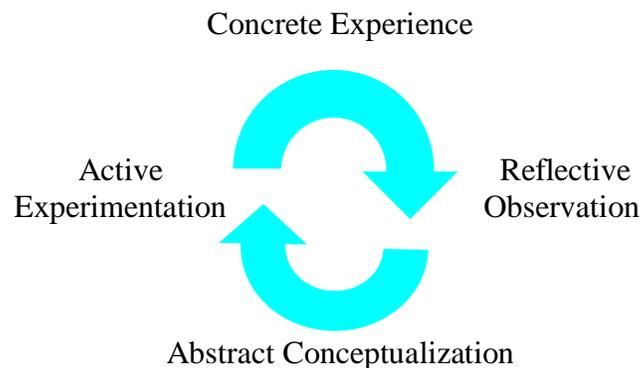
to be superior to the “Full Course”. As the CAD and design are taught in tandem, both can serve as “scaffolding” for the other. Note that it is not impossible to achieve this learning advantage in the stand-alone course. However, a great deal of emphasis would need to be placed on using CAD for real design problems if the stand-alone course were to achieve this same benefit in terms of scaffolding theory.

Felder’s concept of deductive/inductive learning ^{7,8} can be summarized as learning from either the general to the specific (deductive) or vice-versa (inductive). According to Felder, most of our instruction begins with general theories and proceeds to specific applications (deductive) while a significant percentage of students actually learn better in an inductive environment. An obvious way in which to take advantage of this concept would be to provide examples of a method or theory before the explanation of the method or theory is given, e.g. “This is a ‘specific’ example of this ‘general’ theory”. The context of a design project (especially a re-design project where a “first version” of the product actually exists) can provide a specific example for learning of the CAD principles. In this manner, any scenario where design and CAD are integrated would be preferred over contexts in which they are separate.

3.4 Assessment -- The Kolb Cycle

The Kolb model describes an entire cycle around which a learning experience progresses ¹⁸. The goal is to structure learning activities that will proceed completely around this cycle, providing the maximum opportunity for full comprehension. This has been used extensively to evaluate and enhance teaching in engineering ^{26,29,28,30}. The cycle is shown in Figure 1.

Figure 1 – Kolb Cycle



As detailed by Jensen ¹⁴ and Otto ²⁴, the context of redesign currently used at USAFA has been developed to move completely around the Kolb cycle. Integration of a CAD course into this context serves to strengthen three out of the four areas of the cycle. Reflective Observation is enhanced as students specify various parts of their redesign in the CAD package. Abstract Conceptualization is aided by the inclusion of CAD representations of different redesign options from which students choose an optimized version. Finally, Active Experimentation is augmented when students are required to use CAD to check the “fit” and design for assembly of

different parts of their redesign. Clearly, it is advantageous both to the design course and to the CAD course to be framed in this integrated context.

3.5 Assessment -- Amount of Material Covered

The amount of material covered is obviously drastically different in the three CAD options described. The topic coverage varied from 3 to 42 to 15 lessons over the three iterations of CAD instruction, respectively. As mentioned earlier, the 3 lesson “Short Course” was not enough to gain much appreciation of CAD use in design. This course included orthographic drawing and dimensioning techniques and provided a 2-D tool for rudimentary use in future work. Compared to the 42 lesson “Full Course”, the “Short Course” barely scratched the surface.

The “Full Course” incorporated a powerful 3-D parametric solid modeling package and spent the first half of the semester learning the software via a step-by-step tutorial including relations, datums, sweeps, revolves, blends, engineering drawings, assemblies, assembly drawings, and exploded views^{6,31}. The second half of the semester required the engineering design or redesign of a mechanical system of the students’ choice using CAD tools already learned. Examples include an SAE competition off-road vehicle frame and steering linkage, an ASME competition “widget” sorter, and lathe safety chuck. Concurrently, GD&T was taught and incorporated into the new designs in the software package³². Complete engineering, assembly, and exploded view drawings were submitted to a machine shop for fabrication. CAD software interface was explored and utilized with Computer Aided Manufacturing (CAM) using SmartCAM™, Finite Element Analysis (FEA) using ProMECHANICA™ and I-DEAS™, and dynamic modeling using Working Model™. Once fabricated, a design of experiment (DOE) analysis was accomplished to determine success. Formal briefings incorporating CAD models and drawings were presented to all department faculty to wrap up the course.

To integrate 3-D CAD into an already existing design course required an easy adaptation of the “Full Course”. By using the already existing designs/redesigns required in ME 290, all CAD concepts could be employed twice throughout the semester -- applying the new CAD material to the design projects alongside the tutorial as they learned them²⁰. Since only 15 lessons were available, GD&T topics were decreased substantially (though the software supported all ANSI rules automatically) and the use of CAM, FEA, and dynamic modeling, was neglected altogether.

4.0 Ranking the 3 Different CAD Options

A Pugh chart is often used in design to help quantify advantages and disadvantages of different design decisions. In Figure 2, we use this tool to quantify differences between the different CAD options presented above. The left column lists the customer needs critical to the decision. The top row contains the three CAD curriculum options presented. We arbitrarily chose the 3-D “Integrated Course” to be the datum by which other options are measured. The last column, by the definition of “datum” then, is filled with zeros. In order to fill the rest of the matrix, the 2-D “Short Course” and the “Full Course” are measured against the 3-D “Integrated Course” (datum) with respect to that row’s customer need. A value of –1 and –2 are used to indicate minor and major deficiencies, respectively, when compared to the datum. Individual ranking values of +1 and +2 indicate minor and major advantages, respectively, compared to the datum. A zero

indicates no advantage or disadvantage over the datum at meeting the particular customer need. Note that in most Pugh charts, the customer needs are weighted and the weight is multiplied by the individual ranking numbers (-2,-1,0,+1, or +2) before they are added to create a final rank. In this matrix, we have set all of the weights equal to 1. This is done because we believe the weighting will be significantly different in different settings. For example, if a certain engineering department is desperate to reduce the number of courses for their major, the weight on the “material covered” customer need might be 1. On the other hand, if key industrial customers indicate that your graduates lack the depth necessary in their CAD knowledge, the weighting for the “material covered” customer need might be significantly increased.

Figure 2 – PUGH Chart Ranking the 3 CAD Options

CUSTOMER NEEDS	2-D SHORT COURSE	3-D FULL COURSE	3-D INTEGRATED COURSE
Student Feedback	-2	0	0
Professor Feedback	-1	0	0
Consistent with Scaffolding and Inductive/Deductive Learning Theories	-1	-2	0
Covers Kolb Cycle	-2	-1	0
Extensively Covers CAD Material	-2	+1	0
FINAL RANK ORDER	-8	-2	0

As can be seen in Figure 2, the “Student Feedback” customer need has even rank orders of zero for the 3-D “Full Course” and “Integrated Course” options. This is simply because the feedback we received on both courses was very positive. The students were drastically less favorable of the 2-D “Short Course” as is evidenced by its –2 individual ranking. Again in the case of the “Professor Feedback” customer need, the 3-D “Full Course” and “Integrated Course” were considered to be equal. The 2-D “Short Course” was seen by the professors to be slightly inferior to the datum primarily due to the fact that not enough material was covered to be of much real use to the students.

For the customer need of “Consistent with Scaffolding and Inductive/Deductive Learning Theories”, the 3-D “Full Course” and 2-D “Short Course” were ranked slightly and significantly inferior, respectively, to the 3-D “Integrated Course” (datum). The reasons for this ranking are

that, although the 2-D “Short Course” was taught in the context of the design class which provided opportunities for contextual learning (scaffolding) and use of specific examples to motivate general principles (inductive learning), the quantity of content was too small to take full advantage of the integrated environment. The 3-D “Full Course” did not have the built-in advantages of the integrated environment that comes from teaching CAD and design in the same course.

The 2-D “Short Course” rankings from the customer need of “Covers Kolb Cycle” are based on the fact that the shallow exposure in this option precluded movement around the entire cycle. The 3-D “Full Course” is ranked slightly below the datum because in the datum course, the design aspects provided greater opportunity for the “concrete experience” part of the Kolb cycle. The Rankings for the customer need of “Extensively Covers CAD Material” are simply based on the fact that the 3-D “Full Course” covered additional material and the 2-D “Short Course” covered substantially less material than did the datum course.

As is seen in the “Final Rank Order” row of Figure 2, when the customer needs are weighted evenly, the Pugh chart indicates that the 3-D “Integrated Course” (datum) is the preferred choice. We believe that assigning an even weight to all 5 customer needs is reasonable, given the environment at the USAF Academy. Therefore, we plan to continue our current status of offering the 3-D “Integrated Course”. Obviously, if the customer need weights were changed, the final rank order could offer a different optimum solution.

5.0 Conclusion

Over the course of 10 years, the USAF Academy has sought an optimum solution for incorporating CAD into the curriculum. Because ABET criterion and industry requirements are at odds with an ever-tightening engineering curriculum, CAD integration into an existing course is not only necessary, but as shown above, desirable. Incorporating certain customer needs into a decision matrix, or Pugh chart, clearly shows that the student engineer can be readily equipped for future work by integrating design process knowledge with high-power CAD software tools without adding to an already packed curriculum.

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