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Horizontal and Vertical Integration of Design: An Approach to Curriculum Revision*

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The horizontal and vertical integration of design is discussed as a paradigm for redesigning the aerospace engineering curriculum at the University of Cincinnati. The motivation for such change is described in detail together with the educational philosophy developed in response to internal and external information gathering exercises. The general form of the newly proposed curriculum is presented. Finally, the blueprint of the curriculum revision process undertaken at the University of Cincinnati is described for the benefit of future curriculum revision efforts.

MOTIVATION

IN THE Spring of 1992 a volunteer committee was formed in the Department of Aerospace Engineering and Engineering Mechanics at the University of Cincinnati (UC) for the purpose of long-range planning. The charter of this group was to provide overall direction for the Aerospace Engineering and Engineering Mechanics graduate and undergraduate programs including curriculum issues. A review of the undergraduate aerospace curriculum was undertaken based on the following motivating factors:

1. The curriculum has not changed appreciably since the dawn of the jet age.
2. Aerospace engineering is remarkably dynamic technically, each generation of engineers is faced with a greater need to utilize state-of-the-art material.
3. Space engineering is an emerging facet of the aerospace world but has not been addressed adequately in most curricula, including UC.
4. The demographics of upcoming college age Americans will change drastically in the near future, fostering much greater institutional competitiveness.
5. Total quality principles that have been remarkably successful in industry have not been applied throughout the academic community.
6. Industry now faces global competition and requires more capable engineers.

The review consisted of pertinent literature searches, informal contacts with colleagues, several formal surveys [1, 2] of community colleagues and numerous discussions with internal faculty groups. The results of this review confirmed the need for significant curriculum revision and directed its development.

This article describes the newly developed horizontal and vertical design integration philosophy being used to develop a new curriculum and topics related to its implementation. A brief review of current curriculum paradigms is offered to set the stage for the new approach. The strategy undertaken for revision is presented including the educational philosophy to be reflected in the new curriculum, the consideration of 'customer' needs and the iterative top-down/bottom-up mechanics of curriculum building. The new curriculum paradigm, horizontal and vertical design integration, is described in detail including its use in affecting change within the traditional disciplinary, engineering science, basic science and mathematics courses. Lastly, a blue print of the revision process is presented for others interested in curriculum revision.

CURRICULUM PARADIGMS

The eventual form of any curriculum will depend heavily on the chosen or de facto curriculum paradigm. The two most commonly found are based on either disciplinary or unified organizational structures as discussed below. However, as with many issues addressed in the revision process, a curriculum need not be either disciplinary or unified, rather some 'shade of gray' might exist.

Disciplinary structures organize faculty and courses about some identifiable division of topical material. The Department of Aerospace Engineering and Engineering Mechanics at UC is organized with such a structure. Courses are defined as either Dynamics and Control, Fluid Mechanics, Propulsion Systems or Solids and

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Structures. Other identifiable disciplines in aerospace engineering might include (although not at UC) human factors, avionics, manufacturing, etc. The division provides clear lines of responsibility and advocacy for particular course material and allows for significant topical specialization. However, it does not help to facilitate cross-disciplinary understanding for either students or faculty. These walls help to create friction as turf battles are common. In addition, the compartmentalization allows the student to avoid considering factors external to the disciplinary concerns of a given course. This is particularly troublesome when students reach the capstone senior design project and are expected to meld together knowledge in a system design. It also tends to minimize design at the expense of analysis, unless design has the same group status as the other disciplinary courses (not currently true at UC).

In part, unified engineering attempts to correct this deficiency through the creation of high credit hour blocks of engineering material. The traditional set of four/five three credit disciplinary courses is replaced by a single twelve/fifteen credit aerospace engineering course. The disciplinary material is still taught, but in light of rather than in spite of the other disciplines. This presumably allows for greater cross-disciplinary projects and exchanges of ideas. However, from a bureaucratic standpoint it is difficult because lines of responsibility and grading are not clearly demarcated.

In many implementations of the above approaches design is taught primarily within the capstone experience, although a limited amount of design experience is included within the disciplinary courses. However, design can be used as the focal point of the curriculum rather than as an afterthought. Horizontal integration of design essentially utilizes design to link disciplinary courses taught in a specified time period (quarter, semester, year) through a design project. This is somewhat different from a capstone experience which brings together all of the course work in a final project. Rather, the relevance of the current material is brought to life through its application to an ill-defined problem. The advantage is improved student motivation because the analysis now makes sense. It is less ambitious than a unified program, but still requires communication between the disciplines. It also satisfies the bureaucratic efficiency issues since it is taught as a separate course.

Vertical integration of design takes a somewhat different approach to achieve a decidedly different outcome. In it, a series of increasingly complex design projects is performed that are linked in some form to one another. In this way, the relevance of the disciplinary courses is demonstrated at an earlier stage than at the capstone experience. Providing motivation is a decidedly important objective, but this approach does suffer from requiring a long term plan of action. In spite of that, vertical integration still stands alone as a separate entity and allows for the introduction of design ideas at an earlier point in the student's career.

The aerospace engineering curriculum being designed at UC will combine both vertical and horizontal design integration with a disciplinary analysis course structure. Design is the focal, indeed motivating, force for the new curriculum. This approach is the result of our educational philosophy, which was developed in response to extensive information gathering surveys, reported previously by the authors [1], faculty input, and discussions with the Departmental Advisory Council.

EDUCATIONAL PHILOSOPHY

The aerospace community surveys performed earlier [1] stressed the importance of design in all facets of the curriculum, as well as design-related non-technical skills such as teamwork, oral and written presentation, ethics, etc. These results were addressed first by the expression of an educational philosophy, which is now being used as the foundation of the new curriculum. The faculty in the Department of Aerospace Engineering and Engineering Mechanics at the University of Cincinnati believe that a philosophy for a sound educational experience in aerospace engineering should include:

1. *A co-operative learning experience to instill appreciation of current engineering practice in industrial, government and academic facilities.* Note that UC was the first institution to offer a co-op experience and it is recognized that mandatory co-op is a major reason for the success of the College.
2. *High quality education in the fundamentals of mathematics, basic sciences and engineering sciences.* No advanced study can be accomplished without a firm commitment to the basics.
3. *High quality education in a broad spectrum of disciplinary topics.* A broad spectrum of disciplinary topics was chosen so as to give the student the necessary background to pursue a variety of choices throughout his/her career, as opposed to the limited prospects that specialization incurs. This is important because many engineers change jobs and areas of specialization several times throughout their career.
4. *Experience in creative synthesis through the solution of open-ended problems.* The introduction of ideas such as the existence of more than one solution to a problem, the concept of an optimum solution, problems for which no solution exists and over-determined problems are vital to the development of creativity and understanding. These areas were often sited as

being necessary for a graduating engineer [1] and are intimately linked with the successful implementation of horizontal and vertical design integration.

5. *Hands-on laboratory and computer experiences in all major disciplines.* Although considered as somewhat reduced in importance for graduating engineers (as per survey responses [1]) physical laboratory and interactive computer skills are still considered essential by our faculty.
6. *Clear presentations, from the Freshman level on, of what engineering is and what it takes to be an engineer.* Students typically enter with little understanding of the work an engineer does or the basic skills that an engineer requires and employs. These presentations will clarify those traits and give students a more realistic view of the profession.
7. *Faculty development and re-education.* Often fear-provoking, it is apparent that the specialized research area of a faculty member early in his/her career may become obsolete at some later date. The graduate and undergraduate courses taught based on this specialization must also change lest the curriculum become irrelevant. The typical response to this sort of change is either inaction or hiring faculty teaching the now relevant material. Both of these options are undesirable. As such, a more efficient strategy would be to retrain existing faculty and thereby energize otherwise recalcitrant faculty to productive status.
8. *Horizontal and vertical integration of design principles throughout the curriculum.* This approach is proposed to help focus the student on the complex system-based products designed by aerospace engineers. It provides motivation and focus for non-design courses as well and giving the student a sense of purpose and the 'big picture' when taking courses. It also directs faculty to demonstrate the relevance of their disciplinary course. A more complete picture of these relationships will emerge through the discussion of the newly proposed curriculum to be presented next.

It should be noted that an educational philosophy ascribed to by a faculty will depend heavily on their interests and skills. No single philosophy will be correct for all programs. However, what can be in common between programs is the idea that the respective philosophies are reflected in the resulting curricula.

THE NEW CURRICULUM

The philosophical foundation thus laid provides the basis for building a new curriculum, with the last dictum acting as the cornerstone. The horizontal and vertical integration approach makes design paramount to the new structure. The idea is to focus the student experience around aerospace systems and their design. This sets the stage for the iterative design of the actual curriculum. This section discusses the structure of the new curriculum and the strategy employed in its design.

The organizational strategy for the curriculum redesign was based on a matrix structure. Columns of the matrix represent new and existing committees formed to develop the design, basic and engineering sciences, mathematics and disciplinary course content. The rows represent committees devoted to an orderly integration of design and disciplinary courses for a given academic level. The mandatory co-op requirement at UC results in academic levels that consist of three quarters instruction during the Freshman and Senior years and two quarters instruction during the Sophomore, Pre-Junior and Junior years. A total of twelve quarters of academic instruction is allowed with a constraint of no more than 205 quarter-hour credits (not to exceed our current total). It should be noted that although a student requires five years to complete the UC program, the program is not correctly described as a five-year curriculum. Rather, from a course work perspective the program is equivalent to a traditional four-year curriculum.

The committee structure thus described results in an iterative curriculum revision process that is at the same time bottom-up and top-down. The first iteration is based on determining the design content of the curriculum including the capstone course. Design was initially allocated twenty-six quarter-hour credits; three each quarter during the Sophomore, Pre-Junior and Junior years, and eight total during the Senior capstone experience. The content of these courses will be discussed later; however, it will drive the content of the disciplinary courses. This focus on design allows the student to quickly recognize the importance of the disciplinary analysis material when it is applied in the design course either during or immediately after it is taught. The top-down strategy continues by using the design and disciplinary courses to determine the content of the engineering science courses. The strategy then employs all of the above courses to determine the mathematics and basic science course content. In this way, the system design drives the entire process.

Unfortunately, a single curriculum design strategy is not sufficient because outside influences affect the choices. In particular, accreditation bodies have in the past mandated particular content for full accreditation. Even though this is apparently changing the faculty do not feel comfortable dropping the previous standards. Apart from accreditation concerns, university and college requirements place additional constraints on the design. Humanity and social science courses are mandated at the university level, whereas budgetary efficiency and the needs of other programs place important limits on the engineering science courses taught at the college level. These constraints invoke a de facto bottom-up design strategy if for no other reason than as a check against the current design. Hence, both a top-down and bottom-up iteration strategy is used.

Next, the actual form of the proposed curriculum is discussed together with details of the 'pre-capstone' design courses and how they support the capstone experience. In a very general sense the six pre-capstone design courses will begin by presenting significant formal material and short design projects and eventually transition to little or no formal material and more significant design projects.

The Sophomore year will introduce the general concepts and theory of design, emphasizing optimization, statistical issues, and multiple solutions to problems. Case studies will be discussed of generic engineering design problems. Oral and written presentations will be required and students will have a chance to listen to and critique the Pre-Junior level design projects. In this approach both presentation and listening skills are enhanced, an idea present throughout the program. The Sophomore design exercises will be based on mathematics and the basic and engineering science courses already or concurrently taught. Example projects might include designing a table, a computerized casino game or service queue strategy.

The pre-Junior year will introduce and link the aerospace engineering aspects of the curriculum, including aircraft nomenclature and case studies for aircraft, spacecraft and propulsion systems. A fundamental issue will be mission analysis for aerospace applications. Design projects will be presented to the Sophomore class and critiques made of the Junior year projects. Economic, safety and testing considerations will be explored. Design exercises will be based on previous or concurrent course material. Examples include orbit design and design of simple aerospace components, such as a pitot tube, using previous or concurrently taught analysis techniques.

The Junior year will further advance the aerospace component designs by including more advanced analysis techniques. Significant differences include the requirement for knowledge extrapolation, that is, utilizing material not previously or concurrently taught; and the requirement to design, build and test a component. Design exercises might include both structural and aerodynamic design of a wing, including consideration of the propulsion or control system requirements; engine cycles and spacecraft attitude control.

The pace and content of these six courses will be designed to provide the student with significant design experience before the capstone project. The content comes in part from the early weeks of the current capstone experience and from design projects currently given as part of disciplinary classes. It is expected that the capstone experience will now be able to address adequately current engineering concerns, such as environmental issues, cost/benefit analysis, manufacturing and manufacturability, marketing and advanced concepts. It also leaves open the possibility of actually manufacturing the paper design and developing a flight test program.

It is important to note that the emphasis on design will enhance the role of the traditional disciplinary analysis courses rather than minimize them. This focus will improve the relevance of the disciplinary courses and expedite the removal of obsolete material. The disciplinary sequences will be further enhanced by improved awareness of concurrently taught courses in other aerospace disciplinary areas and student recognition of the importance of material currently being studied. It should be noted that this does not preclude the faculty from including additional non-design, background or scientific material, rather it focuses the emphasis onto preparing students with appropriate skills. The same sort of relevancy issues arise again when considering the mathematics, and basic and engineering science sequences. However, in those cases the faculty must work more closely with faculty in other areas to ensure that the requisite material is taught. In effect, this is likely to result in significantly improved communication between faculty, a truly good outcome.

The remaining details of the proposed curriculum are currently being determined. This article was written to describe the general concepts, information gathering and revision mechanics and not to present the final curriculum. The purpose then is to help the reader in his/her own curriculum revision. To that end, the next section discusses the general process followed at UC.

THE REVISION PROCESS

It should be noted that the revision process is at once exciting and full of promise, and at the same time quite frightening. It is, however, necessary for survival. This realization by the faculty is a necessary step before revision can proceed; much like the alcoholic admitting his/her problem before recovery can begin. This section details the general approach taken in curriculum revision at UC.

The first step past recognizing the need for change is to assess what currently exists in the curriculum and how it does or does not meet the needs of the 'customers': the students, their parents, the employer, and the community and nation at large. This process at UC has consisted of several information-gathering surveys, internal discussions with faculty and with the Departmental Advisory Council.

The survey process is described in great detail in previous work [1, 2] and will not be repeated here, however, important lessons learned from this process include:

1. *Faculty input must be solicited early.* They truly have great ideas and must be consulted if success is to be expected.

2. *The revision committee must determine exactly what they really want/need to know.* This is easier said than done and can require a significant amount of effort.
3. *Listening to colleagues who have experience with surveys.* Engineers are not trained in surveying techniques, although they are the only ones who know the content of the questions to be asked.
4. *Questions should be asked so that a numerical response is obtained.* Data analysis is fraught with the inclusion of personal bias and interpretation if non-numerical results are requested.

The results of the information-gathering exercise should be interpreted and analyzed by the faculty as a group. It must be stresses that *total faculty inclusion is the goal*. This will ensure that the general strengths of a program will be preserved and that the talents and desires of the faculty are utilized. A good curriculum will contain these traits. Because of this, it should be recognized that, like any good design problem, there is no single solution to curriculum redesign.

Once understood, the customer needs and faculty desires should be translated into an educational philosophy. Some ideas will be common to most programs, but others (mandatory co-op for example) may not be practical or desired. The philosophy should fit the faculty and the institution, and will partly determine the approach to be taken when performing actual change. The approach to revision must have the support of not only the faculty but the administration as well. Significant effort will be required to plan, deliberate and change courses, which will be quite costly in terms of manpower. It is essential that the administration approve and support the venture before external funds can be reasonably expected.

The above steps are vital to the success of the revision process and, although they may take several years to occur, they are really only the beginning. The 'solution' to the design problem must now be obtained iteratively; the UC approach being described earlier. A plan of implementation must also be determined together with the solution. It is likely to be helpful to determine the implementation schedule early on so that it can be used as a goal to speed the process along. In addition, care must be given to student issues when implementing the change. For example, many current students may be eager to take part in the new curriculum, but there will likely be an equal number extremely opposed to such change. The logistics of any 'interim' curriculum would likely be overwhelming. Because of this, it is suggested that a single class introduce the new curriculum one year at a time. In addition to student concerns, planning should also begin for the hiring of new or retraining of current faculty to fill any voids created with the new approach. The management of change is also important to a successful final result.

Lastly, it has become apparent through the experience at UC that this process should not be a one time event. Rather, the process of re-evaluation and change should be continuous and information gathering surveys should be used to measure success. The process of change is difficult and requires significant 'soul searching' on the part of the faculty, but it is vital to the future success of a program.

CONCLUSION

The horizontal and vertical integration of design has been discussed as a paradigm for redesigning the aerospace engineering curriculum at the University of Cincinnati. The motivation for such change is described in detail together with the educational philosophy developed in response to internal and external information-gathering exercises. The general form of the newly proposed curriculum is presented. Finally, the blueprint of the curriculum revision process undertaken at the University of Cincinnati is described for the benefit of future curriculum revision efforts.

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REFERENCES

1. B. K. Walker, P. D. Orkwis, S. M. Jeng, G. L. Slater, P. K. Khosla and G. J. Simitses, Educating aerospace engineers for the twenty-first century: results of a survey, *1995 Annual Conference Proceedings*, American Society of Engineering Education, June 1995.
2. P. D. Orkwis, S. M. Jeng, B. K. Walker, G. L. Slater, P. K. Khosla and G. J. Simitses, Designing a new aerospace engineering curriculum: the process, *1995 Annual Conference Proceedings*, American Society of Engineering Education, June 1995.

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