VERTICALLY INTEGRATED DESIGN

FINAL REPORT

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OVERVIEW

The SUCCEED project entitled Vertically Integrated Design was meant to explore the possibilities of mixing first year engineering students with engineering seniors in a capstone design course as a means of providing the freshmen with an early introduction to design and with an early appreciation for the direction in which their basic engineering courses were leading. A secondary goal of the project was to expand the program to students in the sophomore and junior years to achieve a full "vertical" integration of the design course and process, making it a central component of the academic program throughout the student's academic tenure. The experiment, after starting very successfully in the above mentioned direction, was considerably broadened to encompass the concept of multi-disciplinary (horizontal integration) design teaming and to include a component of international cooperation.

The Vertically Integrated Design Project at Virginia Tech initially involved the Aerospace & Ocean Engineering Department, the Mechanical Engineering Department, and the Division of Engineering Fundamentals. The ME and AOE departments both had well established capstone design programs in which teams of seniors worked on a year long design problem. The team element was important to this effort since the plan was to have freshmen join the existing teams of seniors in an approximately 1:6 ratio, one freshman becoming a participant in a team of 6 to 10 ME or AOE seniors. This program was very successful as reported in References 1-7. In relatively short order it was obvious that the benefits of the program to all the students involved were so significant that it would be continued with or without continuing SUCCEED support. This conclusion of success was supported by both student and faculty surveys and opinions as reported in the above references. Today the "Freshman / Senior" design program is a permanent fixture in both the Mechanical and Aerospace Engineering programs and freshman selection is coordinated by the Engineering Fundamentals department using well established procedures.

The primary success of the program was in its value in preparing students for later work in the curriculum by making them more aware of the importance of and usefulness of their sophomore and junior level classes in the senior capstone design course. It also seemed to increase the students' enthusiasm for engineering. It also helped the senior students in that having to accommodate freshmen in the middle of the year long design process gave them a much needed opportunity to step back and reexamine their first semester's work and to often make much needed improvements to that work. The program, however, was not found to work as a recruiting mechanism for the majors involved. While it did serve to reinforce the desire of some freshman participants to enter the major of their design group, in just as many cases it caused them to reevaluate their choice of major. Hence, while the experience was undoubtedly valuable to participating students in making a final choice of major, it was not a viable recruiting tool for the participating majors.

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The exportation of this program to other departments in the College of Engineering has been slow despite its success in ME and AOE. Several departments use individual undergraduate research type projects to fulfill their "capstone design" requirement instead of employing a team design program as used by AOE and ME. Other departments, some of which did use design teams in their senior capstone course, seemed reluctant to adopt the program despite its success in AOE and ME. Perhaps, based on the ME and AOE experience, they saw it as too much of a hassle or as having little benefit in attracting students to their program.

In the fourth year of the program an effort was made to try a different tactic to spread the vertically integration of design to other departments through the addition of a "horizontal integration" element. Actually this effort began the previous year but it took a year to make the needed arrangements with the other departments involved. This was to be a multi-disciplinary design project using seniors from three different majors in a single, large team working on a single design problem. The vehicle for this experiment was a new design competition begun by NASA, the Federal Aviation Administration, and the general aviation industry and run by the Virginia Space Grant Consortium. This competition, often known as the AGATE competition after an acronym used by NASA and the FAA to describe their general aviation partnership with industry, encouraged student groups to work on the design of a general aviation aircraft or related system which would help revitalized the industry. It was very broad based in concept allowing students from a wide range of majors to contribute to a mutual design effort, thus offering an ideal subject for a multi-disciplinary design program.

This program was announced by NASA too late in the summer of 1994 for the mechanics of running a large, multi-disciplinary design team to be worked out with the desired engineering departments. When the program was continued the following academic year, however, arrangements were made with the departments of Aerospace & Ocean Engineering, Mechanical Engineering, and Industrial & Systems Engineering to allow students from each department to work together on a general aviation design project while still registering for normal design courses in their own department. This experiment was not without its problems, particularly regarding evaluation and grading of the students' work in the courses. With help from Assistant Dean Pamela Kurstedt, these problems were solved and the experiment was a very successful one. The "vertical integration" goal of the original SUCCEED project was retained as three freshmen were added to the team of 22 seniors during the second semester of the project. Reference 5 gives more details on this 1995 - 1996 experiment.

The seniors who participated in the 1995 - 1996 multi-disciplinary team were, to a large degree, self selected. Announcements of the program were made in the first classes of the design course in all three departments and students were invited to apply. As a result, groups of students who had already planned to work together in their own department's design course applied for this program. This resulted in a large group being made up of a team of 10 AE seniors, two teams of four ISE seniors and a group of 4 ME seniors. It was later felt that this initial self selection of disciplinary teams may have extended the time needed for the development of a sense of team unity among the larger group and a different means of team selection has been used since.

An unanticipated, and very important additional component was also added to the project in the 1995 - 1996 year. This was an international emphasis which included a visit by most of the team members to an engineering school in France for a week of joint design study.

When Dean Kurstedt heard about our multi-disciplinary design team at the beginning of the 1995 - 1996 academic year she invited the team to participate in a program she had arranged primarily for students in Industrial and Systems Engineering in which senior design teams would go to Europe to work on design related problems with students at Ecole des Mines De Nantes, a French engineering school in Nantes, near the Atlantic coast of France. Most of the senior members of the multi-disciplinary design team spent the first week of the Spring Semester in

Nantes working with an equal number of French students on the refinement of their design of a general aviation airplane. The French students were mostly in programs similar to industrial and computer engineering majors in the U. S. and had little experience related to aircraft, none-the-less, the week proved a valuable experience in learning to work on teams with people from another country and to communicate with people who usually speak a different language. As reported in Reference 5, this international experience proved a valuable experience in preparing our students for work in today's international marketplace and also proved to be an important catalyst to help to further unite this team of students from different majors who had tended to want to work only in discipline specific sub-groups prior to the trip.

After the valuable learning experience of the 1995 - 1996 academic year we felt much more confident in continuing the multi-disciplinary design program for a second year and SUCCEED funds were tapped to support the international portion of the experiment which had proved very valuable in the previous year. Unlike the year before, the international component of the program was planned in advance in the 1996 - 1997 experiment and students were selected for the multi-disciplinary team knowing of the trip in advance; thus, all the team members for the fall semester were able to fully participate in the international trip late in that term.

Another major objective of the 1996 - 1997 program was to finally expand our experiment to include students at all undergraduate academic levels. This meant adding sophomores and juniors to the program. For the first time in the SUCCEED sponsored project we would have a totally vertically integrated and horizontally integrated design team!

During the summer of 1996 the process of selecting five seniors from each of three majors (AE, ME, ISE) was started . Invitations were sent out to twice as many students as were needed for the team and the 15 senior participants were selected from those responding to the invitation. Invitations were tendered based on the desire to get a well rounded group in terms of both technical interest areas and personality and to have a balance of men and women reflecting the population in the College of Engineering. While no students in academic difficulty were invited to apply for the team, grade point average was not a primary consideration in team member selection. Indeed, some of those selected expressed surprise at being chosen despite their gpa. Five juniors, all from Aerospace Engineering, were similarly selected for the team.

The AE juniors were to participate from the start of the year as full members of the design team, using their work both to satisfy a design mini-project for their Aerodynamics class and for a two credit "independent study" course during the fall semester. In the spring term they would sign up for a three credit independent study in general aviation airplane design.

Sophomores were also being included in the experiment for the first time and they were to be added to the team in the spring semester along with the freshman participants. Five freshmen and five sophomores were selected for participation in the spring. As usual, the freshmen were chosen from applicants by the Engineering Fundamentals Assistant Department Head. The sophomores were selected from students in one of the AOE Department's Aircraft Design course sections who expressed an interest in the project. The primary task of the freshman and sophomore participants was to help with CAD drawings needed in the design process and to build and wind tunnel test a model of the designed aircraft. This proved to be not only a very interesting assignment for the students involved but also provided a real asset in later publicity efforts for the program. There is nothing like a well made model to attract attention at a meeting.

Thanks to financial support from SUCCEED, an international component of the 1996-1997 program appropriate to the general aviation design topic could be planned well in advance. Arrangements were made with Ecole Nationale Superieure D'Ingenieurs de Constructions Aeronautiques (ENSICA), an aerospace engineering school in the heart of the European aerospace

industry in Toulouse, France, for our 20 person team of juniors and seniors to work on the design of a prototype of a sport aviation amphibian aircraft based on an earlier student design at ENSICA.

Thanksgiving week is not the ideal time to visit France and it rained nearly the entire week, combining with the ever recurring pre-holiday strike of French transit workers to make the teams week of study an interesting one. The week was quite successful in spite of the strike and the rain and, in addition to spending many hours in the design lab working with their French counterparts and with ENSICA faculty and industry leaders from the Toulouse area, the group was able to tour several local industry complexes and was able to enjoy a reception hosted by the mayor of the city. As in the previous year, the international trip helped considerably in bringing the multi-disciplinary team closer together and to help break down their initial tendency to want to work in sub-groups related to their major. Although many of the aspects of the design project could seem primarily related to one or the other of the students' disciplines there was a considerable degree of cross-major interest exhibited within the group, especially after the French trip.

Based on surveys of the students who participated in the 1996 - 1997 program the addition of the sophomores and juniors to freshmen and seniors of past design team experiments; i.e., the first full vertical integration of the program, was a resounding success. The juniors very successfully took on leadership tasks normally done by seniors and the sophomores became very proficient wind tunnel model builders. All students, freshman through senior, participated in developing, writing and making an oral presentation of the team's final report.

The success of the 1996 - 1997 program was further confirmed when, at the Experimental Aviation Association Convention in Oshkosh, Wisconsin on August 1, 1997, NASA Administrator Daniel Goldin presented the team an award plaque and $1000 check for third place in the NASA / FAA General Aviation Design Competition. This was the only award going to a team which had freshmen, sophomores, and juniors and had seniors from three different majors and faculty from the first and second place award schools were quite surprised when they found that the outstanding project presentation given by our team at Oshkosh was given primarily by underclassmen. The team's model, a product of freshmen and sophomore efforts, also drew the attention of the crowd at the presentations and was used by NASA as the centerpiece at their press conference for the meeting. The professional level of the team's work has resulted in many requests for more information on the design and even in questions about the availability of a final production version of the design. Appendix A of this report is a copy of the Executive Summary from the report of the 1996 - 1997 multi-disciplinary design team.

The overwhelming success of this SUCCEED project has already captured the interest of several aerospace companies and explorations are now under way for funding from two major companies to support the program in future years. Industry representatives have praised the program for its multi-disciplinary team approach to design education and for its importance in preparing students to work in the truly international marketplace of the aerospace field. Based on preliminary indications we fully expect enough industry funding to support and even expand this program in the coming years. Meanwhile the College of Engineering is providing support for the international part of the program for the 1997 - 1998 academic year and has promised to match industry contributions in future years.

The goal of the NSF in establishing the engineering education coalitions was to create academic program changes and enhancements which would become self supporting and which would be "exported" to other departments and universities. Almost every aspect of this experiment in vertically and horizontally has proven successful and will be continued at Virginia Tech without NSF support. The task now is to export this concept to other schools where we are confident that equal levels of success can be experienced.

PROGRAM CONTINUATION AT VIRGINIA TECH

As mentioned above, this program has been an unqualified success by all measures (assessment of this success will be discussed in a later section). The experiment has gone well beyond the original concept, expanding to cover both horizontal and vertical integration of the capstone design course and adding a very successful international component. The academic departments which have been involved are very enthusiastic about the program thus far and all have plans to continue.

The original vertical integration concept of adding selected freshmen to existing senior design teams has been a success from the start in both Aerospace Engineering and Mechanical Engineering. This program has been expanded to include Ocean Engineering and, through the multi-disciplinary design program, to Industrial and Systems Engineering. Work will continue to expand this program to all other engineering majors which use a team design project as their capstone course.

The multi-disciplinary design program grew out of this project and quickly became the project's primary experiment. Multi-disciplinary design projects had been used in the college on an informal basis in the past but none had been formally made part of the academic program allowing students in several majors to work on a single design project while still registering for their own, in-major design course or sequence. This experiment has shown that to be not only workable but also very attractive to students. This program continues to be expanded. During the current (1997 - 1998) academic year students from two new departments, Electrical Engineering and Materials Engineering, have been added to the multi-disciplinary design team which also includes students in AE, ME, and ISE. The task which remains is to convince other faculty and departments to offer such multi-disciplinary design opportunities for students.

The international experience provided by the cooperation between Virginia Tech and various engineering schools in Europe for the general aviation multi-disciplinary design team has excited participating students as well as college administrators and several major aerospace companies. This is continuing in the 1997 - 1998 academic year with financial support from the College of Engineering. Arrangements have been made for the design team to travel to Loughborough, England over the Thanksgiving break for a week of study with a team of aircraft design students there. Dr. Lloyd Jenkinson of the Aeronautical Engineering program at Loughborough University will come to Virginia Tech in October to meet our design team and work with us on continued planning for the joint endeavor. Current plans are for both the English and American design teams to work toward the same design objectives to develop final designs in a friendly competition. Thanks to the internet (Web sites for both schools and e-mail) communication is relatively easy and the students and faculty involved can work together just as if they were in the same room with only the 6 hour time difference being a problem.

Future plans for international cooperation with this project include expected funding from one or more major aerospace companies to pay for student travel. The hope is that in future years students from both schools will be able to visit the "other" university during the year, working together on two occasions on a common project. We are certain of continuing cooperation with both ENSICA in Toulouse, France and the University of Loughborough in England. We have also begun to explore similar joint efforts with one or two universities in Korea. The hope is to continue to make these trips at no cost to the participating students; however, it would not be unreasonable to propose that participants pay 50% of their costs in future years if it will help the program expand.

PROBLEMS

This program started as an effort to bring freshmen into the senior design process as a mechanism for encouraging their interest in engineering and giving them a better vision of their academic program goals which would cultivate a better appreciation for their more generic freshman, sophomore, and junior level courses. This has worked. In exchange, the freshmen, who at Virginia Tech are required to own personal computers and who have the latest versions of sophisticated CAD programs, were to bring that CAD expertise to the design teams. This worked very well in the first year or two of the program but, due to changes in the CAD software used and to new changes in the freshman curriculum, has had decreasing success and an uncertain future.

In the first year of this experiment the freshmen engineering students at Virginia Tech received CadKey as their engineering graphics CAD program and were given instruction in its use in their second semester Engineering Fundamentals course. Those who participated in the Vertically Integrated Design experiment were expected to use that software in their design team work and to use that work to satisfy a CAD project requirement in their EF course. This worked very well since, with CadKey, the students quickly gained proficiency in CAD. The result was some quite sophisticated CAD work by the freshmen. One of the freshman participants in our program even won a national award for his CAD work on an aircraft design project. Unfortunately, student proficiency in CAD had progressively declined since that time due to a college level decision to change CAD software.

About a year after this experiment began the College of Engineering decided to switch from CadKey to AutoCad. The primary reason for the change was the impression by both students and faculty that AutoCad was much more of a mainstream product than CadKey. The Engineering Fundamentals faculty fought against the change, noting that CadKey was a much better learning tool than AutoCad, but this was ignored by those who saw the latter program used more in the "real world". Unfortunately, the EF faculty proved prophetic in their belief that the "learning curve" with AutoCad was much steeper than with CadKey. The result has been a precipitous decline in the CAD capability of the freshmen as we went from CadKey to AutoCad-12 to AutoCad-13. This resulted in a severe decline in the ability of the freshmen to make significant contributions to the design process. By the time they have reached a level of ability sufficient to do the type drawings needed in a final design report or presentation it is too late in the term to be of much use to the design team effort.

The future of freshman involvement is very uncertain at this point due to the CAD question described above and due to more recent changes in the Engineering Fundamentals courses taken by the freshmen. Significant changes have been made in the engineering freshman year at Virginia Tech in response to a few influential departments which no longer see great value to a common first year or to common instruction of all engineering freshmen in such things as computing languages and/or CAD. The result has been a severe dilution of the material covered in the first year Introduction to Engineering classes with the assumption that the individual majors will supplement this coverage with their own required material.

One possible solution to this problem may be to limit participation in the vertically integrated design program to those freshmen who are enrolled in certain courses, such as a special CAD course. Another solution is to discontinue the involvement of first year students in the project, replacing them with sophomores. The latter may prove the most satisfactory solution to the CAD problem; however, it has the drawback of giving up on the idea of using the program as a means of helping freshmen get a better sense of direction in their engineering careers. We are in a wait-and-see mode on this question until we gain some experience with our revised freshman year.

PROGRAM ASSESSMENT

A continual program of assessment accompanied this entire project. Each semester all participating students were surveyed to ascertain the degree of success with which freshmen and other non-seniors were integrated into the design teams and, over the past two years assessment has also covered areas relevant to the multi-disciplinary and international aspects of the project as they have been added to the program. A final overview assessment of the entire program was conducted this summer with an study of the effect of the project on all underclass participants since the project began.

The annual project assessment efforts and their results have been thoroughly reported in References 1 - 4 and these will not be repeated in detail here. The overwhelming outcome of the program has been an indication of success in meeting every goal originally established for the project. Freshmen participating in the program have expressed great enthusiasm for the project and have become leaders on design teams established in classes in their later studies. It has been interesting to note that when freshman participants have reached the senior year they have usually been leaders of their own design teams and have been strong advocates of continued freshman participation and have proved excellent mentors for the freshmen working with their design groups.

It was interesting to note that in the second year of the program one of the AE senior design teams was very much opposed to the inclusion of freshmen on their team. They had a group of ten seniors who wanted to work together on a design as part of an aircraft design competition run by the American Institute of Aeronautics and Astronautics. The AIAA has a 10 person limit for teams in their design competitions. This meant that no freshmen could be added to the team if the team membership was to remain within the limits. Dr. Mason, the design professor involved, forced the team to reduce its membership to eight to allow inclusion of two freshmen in the second semester, a requirement that proved upsetting to the team's seniors for the entire year. Even under these circumstances, the freshmen added to this team gave the project excellent reviews at the end of the year. The seniors on the team reported that they did not do anything to make the freshmen feel part of the team, yet, the freshmen both reported that they were made to feel very welcome by the rest of the team. The seniors were willing to admit that the freshmen had been good members of the team. In light of the year-long carping of this team's seniors about Dr. Mason having broken up the "perfect team" we viewed this grudging admission of the freshman contribution to the team effort a real success!

It should be noted that each year in the survey of freshmen who have participated in the project the respondents note that they did several times the amount of CAD work as their non-participating peers but that they enjoyed the experience and would recommend it to the next year's freshmen.

Last summer, as a final assessment of the project's success, we examined the records of the 143 freshmen who had participated since the start of the Vertically Integrated Design Program in spring 1993. Appendix B gives complete data on all of these freshmen including the year in which they were participants and the department whose senior design team they joined. Their grade point average (known at Virginia Tech as a "QCA") is given for each term of their enrollment. (A CEP notation in a term indicates participation in the university's Cooperative Education Program.) Also shown is their "overall QCA or grade point average as of summer 1997, a check if they were in the Co-op program, a listing of their academic majors while at Tech, any distinctions received upon graduation (if they have graduated), their current academic major and their date of graduation.

The data in Appendix B can be summarized as follows for the freshmen, all of whom were in General Engineering when they participated in the program:

Participants by year:	1993	1994	1995	1996	1997	TOTAL
	29	22	34	21	37	143

Department of design team in which the freshmen participated and the related number of students:

Dept.	AE	ME
Participants	47	96

Retention information on participating freshmen:

Stayed in major:	63	(AE 24, ME 39)
Stayed in engineering but in another major:	44	
Switched to major other than engineering:	6	
Dropped out of school:	5	
Academic Probation:	1	
Status unknown	24	

Academic information:

Average QCA (GPA):	2.98	(AE: 3.05, ME: 2.95), Range: 1.65 - 4.0
Graduated:	30	

Graduated with honors: 9 AE: 6, ME: 3)

A final survey was also sent to all of the 143 former freshman project participants for which a correct address could be found. This survey form is shown in Appendix C. The response to the survey represented about 15% of the participants spanning all the years of the project and is felt to be statistically significant. The results are summarized below with the average level of agreement to each statement on the survey given at the end of the statement. The range of responses could vary from 5, indicating strong agreement with the statement, to 1, which indicated strong disagreement. A response of 3 was to be used for a “neutral” response.

	Survey statement	average response
My participation in the SUCCEED program:		
1.	played a role in my choice of major.	4
2	affected my selection of classes and electives.	4
3.	helped me choose my senior design project.	3.3
4.	prepared me and gave me the ability to face the challenges of a design project.	4.5
5.	raised my academic standing in the university (grades)	3.8
6.	I feel the SUCCEED program increased my potential for employment, a co-op position or a summer internship.	4.3
7.	I feel that my efforts were beneficial to the design on which I worked.	4.1
8.	I was welcomed into the design group and not made to feel that I was in the way.	4.5
9.	The work required for the design project was too much and conflicted with my normal work load.	2.29

These answers, some coming as much as 5 years after a particular student originally participated in the project as a freshman, are very consistent with those received in surveys taken immediately after the semester of participation.

Perhaps more interesting were the written comments in response to the last three questions on the survey. Listed below are some of the responses to each question:

How important do you feel the design experience is to your educational background?

"The design experience I received as a freshman was very important to understanding the whole picture and all that is involved in a senior design project."

"The experience is very important. The sooner you get the feeling for solving real life problems the better. It puts all your classes into perspective"

"I feel that I am miles ahead of my classmates as a result of this project."

"The design experience provides an excellent forum for one to apply in a meaningful manner the theory and problem solving skills that may otherwise be forgotten due to lack of use. Now, in each class that I take, the methodology for each type of problem is stored in my memory with a real-life problem that is applicable; hence, I have better memory retention of the subject."

"The design problem is very important in that it forces participating students to learn how to be creative as in creating something, not necessarily with the 'innovative' overtones the word carries -- instead of purely analytical problem solving. Relatively little is given for students to start with, they must learn on their own and in cooperation with teammates, in order to arrive at their best answer -- not the best answer. Not every conceivable permutation of a solution can be evaluated so students develop judgment at every decision. There is no authoritative, omniscient source, and this requires students to work themselves at choosing solutions."

Do you feel the SUCCEED program should continue? Would you recommend this program to other freshmen?

"I strongly feel it should continue and I would definitely recommend it."

"Yes, it should continue. I have recommended it myself already."

"It definitely should continue and I definitely would recommend it to any incoming freshman simply because I learned so much."

"I would strongly recommend it to freshmen."

"The program is invaluable to the education of engineers that can not only solve problems but solve those that pertain to real-life problems that arise within teams that are now the standard in the engineering world."

"Yes. I would recommend it to each and every freshman! It was beneficial and got me excited about engineering."

What lessons did you learn during the program that you feel weren't taught or covered in your other engineering courses?

"I learned something about how to approach a senior design project when it comes time. I saw how the seniors in my group put too much off until the end which is easy to say bur hard to do. I am definitely happy with the project and hope it continues."

"Everything I learned on the project was not taught in my freshman year classes. That is why I feel I have a head start compared to others in my class."

"I believe the strongest lesson learned was that you should not be timid in testing and designing and that the best way to get things moving (educationally or groupwise) is to jump right in and give it a try."

"I learned that design doesn't always start with calculations. Instead, I found that it started with an idea and a great deal of research. The program also showed me that the team effort is the only way to achieve a realistic goal; something that I didn't really understand in the highly individualized theory classes."

"Notably, I was shown the importance of planning together within the design team the details of what parts of the project will need to be completed by what time; that is, because all are working on interrelated aspects of the whole design, it is necessary to have coordination in technical development of the design as well as in the processes and procedures that coordinate that development."

"The biggest lesson was how to get along with others in a group of that kind. You had to be considerate and take everyone's ideas into account! It is very important to learn teamwork since teams are the wave of the future. Also participation in the design process is much different than memorizing steps."

It seems from such comments as these that the vertically integrated design program was very successful at meeting its goals. The only disappointment has been the failure, in spite of the obvious success of the project, for other departments besides those already involved to actively participate in the program.

As pointed out previously, the multi-disciplinary aircraft design project, started in 1995, has involved a couple of other departments in a different way; however, no other department has chosen to become involved in the original intent of the project, to have engineering freshmen join their own senior design project teams. Perhaps the primary reason for this is the small number of departments which use the team approach in their senior, capstone course, if they even have such a course. This is quite surprising at a time when industry is constantly reminding us of the need for team experience and design experience in engineering graduates.

Our largest department, Electrical and Computer Engineering, does not even have a specific design course in their curricula and claims to satisfy ABET capstone requirements with a "capstone elective" requirement which is usually some sort of individual research project. Civil Engineering, another large department, also has no specified capstone design course in its curriculum but has certain courses designated as "design project" courses with a "group approach". Many of the other departments have project courses which usually involve students working on individual projects with a faculty advisor. The recent expansion of the scope of the program to include multi-disciplinary teams is partly an attempt to remedy this problem. This effort is too new for a meaningful assessment other than that already mentioned which indicates considerable student enthusiasm for the projects.

CONCLUSIONS

Over the course of five or six years the "Vertically Integrated Design Project" has evolved into the "Vertically, Horizontally, and Globally Integrated Design Project". The plan to involve engineering freshmen in senior design teams has proved very successful, however, the future of the effort may lie more in its "horizontal and global" components than in the "vertical". Indeed, the vertical component may only be achievable in some majors through their involvement in multi-disciplinary student design projects. This is especially true where a department has no team based, senior level, capstone design project requirement in its curriculum, a situation which the authors were surprised to find existing in a majority of engineering majors at Virginia Tech. In view of the importance of interdisciplinary team approaches to design in "real world" industry and of industry's apparent interest in promoting this type of effort in the university, the "horizontal" integration of design through teams may be a more important issue than "vertical" integration.

There is no question that vertical integration of students into the design process early in the engineering curriculum is of great value to the students' education. All the outcomes of this phase of our project confirm this. This experiment has worked very well in Aerospace Engineering and in Mechanical Engineering at Virginia Tech; however, it would be a real problem to expand this effort to include all freshmen who might be considering those two majors. There simply aren't enough seniors to go around. We found that vertical integration works well when freshmen are mixed with teams of seniors in a ratio of about 1:5 or 1:6. It would obviously be an entirely different problem to include large numbers of freshmen and, in the limit, would become a senior/freshman mentoring program.

We have found a very real industry interest in capstone design course efforts involving multi-disciplinary teams and in a program which uses such teams in a global collaboration with schools in other countries. While bringing students from several engineering (and perhaps even non-engineering) majors into a single design team is not without its difficulties, it is an achievable goal, even at schools where some majors do not normally use team design approaches. It, in fact, offers a way to introduce the team design concept into programs which normally do not use it. The 1997 - 1998 Virginia Tech General Aviation Design Team is a test case for this where students

from 5 departments are working together on a single project and where two of the departments from which participating students are drawn do not normally use team design projects.

Taking the "integration" concept further by having students from schools in two different countries work together appears to be a workable extension of the project. It is, however, expensive, and if it is to be open to students of all financial means it must have some level of sponsorship. Industry may be interested in such efforts but one is not likely to find either industry or government funding to take all engineering students to Europe as part of a design project. The Virginia Tech programs have cost about $1000 per student if housing was provided by the European host school. This is a very reasonable cost and many students would be able to raise their own money to participate in such a project but some source of funding would have to be found for qualified participants who could not afford the price.

This project has, therefore, explored three very viable processes of design integration: vertical integration in which freshmen, sophomores, and/or juniors joined seniors on capstone design teams; horizontal integration, where seniors from different academic majors work together as part of a design team on an interdisciplinary design project; and global integration, where design students from an American engineering school collaborate in some way with students from another country to work on a single design project. All three concepts have been shown quite workable and to offer great benefits to the participating students and faculty. These concepts should be viable individually or in combination, offering any engineering college a range of options suited to its mission and goals. Our next goal as part of the second five years of SUCCEED is to export these concepts to other departments within the Virginia Tech College of Engineering, to other universities in the coalition, and to schools throughout the country.

REFERENCES
(And list of publications from this project)

1. Marchman, J. F., III and W. H. Mason, "Freshman/Senior Design Education", AIAA Paper 94-0857, Aerospace Sciences Meeting, Reno, NV, January 1994*
2. Mason, W. H., Eiss, N. S., Pusey, R. H., Marchman, J. F., "Freshman-Senior Design Teams: Experience at Virginia Tech", First Annual SUCCEED Conference, Raleigh, NC, March 1994
3. Marchman, J. F, and Mason W. H., "Incorporating Freshman/Senior Design into the Aerospace Curriculum", ASEE Annual Conference, Edmunton, Canada, June 1994
4. Mason, W. H., "Aircraft Design at Virginia Tech: Experience in Developing an Integrated Program", AIAA Paper 95-3894, 1st Aircraft Engineering, Technology, and Operations Conference, Los Angeles, CA, September 1995
5. Marchman, J. F., "An AGATE Inspired Program of Interdisciplinary/International Design Education", ASEE Annual Conference, Washington, DC, June 1996
6. Mason, W. H., et.al, "Early Design: Lessons and Strategies from SUCCEED", Session 3225, ASEE Annual Conference, Washington, DC, June 1996
7. Marchman, J. F., "A Multi-National, Multi-Disciplinary, Vertically Integrated Team Experience in Aircraft Design", AIAA Paper 98-0822, Aerospace Sciences Meeting, Reno, NV, January 1998

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