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Multinational, Multidisciplinary, Vertically Integrated Team Experience in Aircraft Design*

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An experiment in team capstone design education which began by adding engineering freshmen to traditional senior design groups has expanded into one involving freshmen, sophomores, juniors, and seniors in a large, multidisciplinary design team. The experiment has also broadened to include an international design experience by having American design students work with their peers at European schools. This multidisciplinary, international design approach has resulted in a valuable experience for its participants who are much better prepared for the team environment found in industry today and for today's era of multinational aerospace programs.

INTRODUCTION

FEW ENGINEERING graduates are truly prepared for work in today's industrial design environment, as spokespersons for industry continually note in their calls for more team experiences and interdisciplinary work for students. Many engineering departments have only recently embraced the concept of students working in teams, usually within the senior, capstone design project. Some engineering colleges have developed highly publicized design programs for students at levels other than the senior year but few of them have attempted to vertically integrate their design experience; i.e., to combine students at several different academic levels to work on a single design project. It is even more rare to find programs which have attempted to forge multidisciplinary design experiences for their students, combining students from several academic majors into design teams. Yet all of this is part of the real-world engineering work environment where members bring the strengths of various disciplines and levels of experience into a product development team.

Today's aircraft market is also truly global in scope, with intense international rivalries in aircraft sales and the need to form multinational aircraft development, manufacturing, and marketing alliances in order to survive. Engineers working for aircraft manufacturing corporations must be able to work with their counterparts from other nations on design and development teams, a task always complicated by language differences and often made more difficult by differences in culture and expectation. It is important that today's engineering graduates be able to not just work in but also to excel in this international environment.

Almost totally lacking in today's engineering educational experience is the opportunity to participate in any sort of multinational team design or development project. While many engineering students have studied a foreign language, language itself is often less of a problem than other factors in creating an effective multinational teamwork environment. Cultural differences which determine the various team members' expectations of themselves and others are usually more of a barrier to success than language. One sees these in every society in such things as attitudes towards women in the workplace, differences in work ethics, the tendency in some cultures to praise every effort no matter how unproductive or an obsession with absolute perfection in other cultures, etc. It has been said, for example, that the French engineer insists on studying a project to death seeking perfection even if no product ever results, while the American engineer's desire is to get a working product to market as soon as possible and fix any problems later.

Most American engineering students get the majority of their team experience through the senior, capstone design course, working only with other students in their own major and only with other American students. They are definitely not prepared to enter a global engineering environment, and probably have little or no experience in working with students outside of their own academic major. It is time for this to change. The following material describes a program developed at Virginia Tech to better prepare today's engineering graduate for success in a world in which multidisciplinary, multinational design and development teams play an important role.

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PROGRAM EVOLUTION

In the early 1990s the National Science Foundation created an Engineering Education Coalitions Program designed to support efforts by coalitions of colleges of engineering from various universities to create new visions of engineering education. One of the coalitions funded under this program was the Southeast University and College Coalition for Engineering Education (SUCCEED), which included the colleges of engineering at Virginia Tech, N. C. State, North Carolina A&T, Clemson, Georgia Tech, Florida, Florida State, and Florida A&M.

Freshman/senior design

One of the projects supported by the SUCCEED coalition was the Vertically Integrated Design Program at Virginia Tech. The initial goal of this project was to create a design education model in which freshmen, sophomores, juniors, and seniors all worked together in design teams on long-term (semester or year-long) design projects. The experiment began by adding freshmen to existing teams of seniors in capstone design courses in Mechanical Engineering and in Aerospace Engineering. The freshmen, who studied CAD in their second semester Introduction to Engineering course, would contribute to the CAD effort of the senior design teams during the second semester of the senior design course. The CAD work of the freshmen would replace the CAD requirement of the Introduction to Engineering course.

This effort [1–3] showed that freshmen could not only make valuable contributions to their design team's work, but could also gain significant insight into the design process and into the importance of the courses to follow in their academic program, both of which could greatly enhance their continued academic career. Surveys of the freshman participants also showed that, although they spent considerably more time working on the design teams than their peers spent on their regular CAD projects, the project participants felt that their experience was far more satisfying than that of their non-participating peers.

The original intent of the Vertically Integrated Design Project was to eventually add sophomores and juniors to the design team mix but this objective was delayed by the success of the freshman/senior experiment and the result it had on the curriculum without further expansion. Students who had participated in the experiment as freshmen wanted more design in the sophomore and junior year and there were simply not enough existing senior design groups in the participating departments to accommodate students other than the freshmen. It was also obvious that it would never be possible to include more than a small number of freshmen in the program since the number of freshmen exceeded the number of seniors. Meanwhile, attempts to interest other Virginia Tech engineering departments in the experiment failed because most of the departments still did not require team projects for their so-called capstone experience or because they did not want to deal with the extra work required to co-ordinate such an effort.

The Aerospace and Ocean Engineering Department reacted to the increased student interest in design which resulted from the freshman/senior program by creating a new sophomore level Introduction to Design course. This course has proven a popular elective. The department also added mini-design projects to selected courses in the junior year. The result of this was that the freshman/senior design program was not expanded to include sophomores and juniors for several years as other design-related changes in the curriculum occupied the time of the project directors.

Multidisciplinary design

The opportunity for further program change came in response to the creation of the NASA/FAA General Aviation Design Competition in 1994. This competition, developed as part of efforts to revitalize the general aviation industry in the United States, seemed the ideal basis for the creation of a multidisciplinary design team project at Virginia Tech. The idea was to create a general aviation design team including seniors from the departments of Aerospace Engineering, Mechanical Engineering, and Industrial & Systems Engineering.

The announcement of the GA Design Competition in summer 1994 came too late to allow its use for a new multidisciplinary team effort in the 1994/1995 academic year because the ME and ISE departments were not willing to proceed with such a plan on short notice; however, the way was prepared for formation of such a team the next year if the competition continued. When the second year GA Design Competition was announced, the three departments (AE, ME, and ISE) agreed to participation involving a few of their seniors in a multidisciplinary team to design a general aviation airplane. A team of 24 students was selected from volunteering seniors in the three majors at the beginning of the academic year. Freshmen planning to enter all three majors were also added to the team in the second semester. Despite some initial difficulties in satisfying the varying organizational expectations of the three participating academic departments, the project was a success. The students, who at first had serious doubts about the abilities or interest of the participants from other majors, eventually overcame these difficulties to work as an effective team on their design problem.

An unplanned opportunity to broaden this multidisciplinary design project into one involving international co-operation played an important role in forging these diverse students into an effective design team.

Multinational design

As reported in Reference 4, the College of Engineering, upon learning of this multidisciplinary design project experiment, offered to turn it into an international experience by sending the team to France to study with a team of French engineering students at Ecole Des Mines De Nantes. The trip to Europe was preceded by extensive interchange among the French and American participants via e-mail and two-way interactive television. This international part of the experiment, as expected, proved very beneficial from several perspectives. It helped the American students achieve a better focus on their own design project than would have been possible without their work with the French students. It was also a very revealing experience in terms of understanding how to overcome cultural and language barriers that can easily bring co-operative design and development programs to a standstill.

Talks by American and French industrial leaders and chats with students and faculty at Ecole Des Mines, revealed significant differences in the engineering cultures of these two countries. The American female students were told by their French counterparts that women are rarely allowed to lead teams in their country and do not have the same opportunities for advancement as American female engineers. This was confirmed by French industry spokesmen, as was the fact that French engineers are much less applications oriented than American engineers, often seeking perfection in the design of their products over practicality. Despite these differences, the students found that beer and pizza are all that is needed to break down all international cultural barriers.

One of the most important aspects of this international experience had not been expected. The trip was very effective in enhancing the teamwork of the original multidisciplinary group of American engineering students. All of the students reported that being together in a foreign culture did more to unify them as a team than any of the other organizational or team-building exercises they had tried. It is revealing that one member of the American team was an industrial engineering student from Spain who noted that, although he had lived in the United States for several years and had known some of the other students on the team for years, it took the trip to France for him to really get to know American students.

The multidisciplinary, international design experiment described above was conducted in the 1995/1996 academic year. Its success led to another ambitious expansion the following year (1996/1997) under SUCCEED sponsorship. As in the previous year, the team included AE, ME, and ISE seniors. Five seniors from each discipline were selected from those who responded favorably to a mailed invitation during the summer. Selection was based on a combination of factors, including the desire to get a balanced team in terms of interest in the various subjects (aerodynamics, structures, manufacturing, ergonomics, propulsion, etc.) which would play an important role in the design process. Unlike the previous year when there was no preset number of participants from each major, the selection was limited to five seniors from each major. Five Aerospace Engineering juniors were also selected in a similar manner for participation in the group.

It was interesting to note that, unlike the previous year when self-selected student groups from the three majors were brought together into one large team, in this second year the students were almost randomly selected for participation, joining other students they may have never met. This selection process seemed to work better than the self-selection system in terms of producing a smooth running team. Perhaps with self-selection, where students form their own teams from groups of friends, student expectations of their friends' performance on a design team do not end up matching reality. Expectations based on past social interactions do not always pan out in a work environment and tensions result when, for example, the friend who was always reliable in bringing the keg to the party turns out to be somewhat less reliable in bringing the performance estimates to the design team meeting. When team participants are selected or assigned by some other process, unfulfilled expectations do not get in the way when the team is developing a working relationship.

In an attempt to speed the process of team building a session of exercises was conducted by a specialist in the area and the trip to a foreign school was moved into the fall semester. The team of 20 students went to Toulouse, France over their Thanksgiving break to work with a team of French engineering students at ENSICA and ENSAE, two top French Aerospace Engineering Schools. Faculty from these schools and representatives from the French aerospace industry also participated in a joint design case study of a two-passenger, general aviation, amphibian sport aircraft. Prior to the trip, partly because of the topic to be studied in France, the team had elected to work on the design of a four-passenger amphibian plane. The week in France was one of rather intensive design study mixed with tours of several European aerospace facilities in the Toulouse area. The trip was very valuable in several ways. The students gained experience in international relationships; learned a significant amount of information about general aviation amphibian aircraft, and about manufacturing and testing. Also, as with the previous team's experience in a foreign country, the trip helped the students to see themselves as a team instead of a collection of ME's, IE's, and AE's.

More vertical integration

As in the previous year, freshmen were added to the team in January, but this year an equal number of sophomores from Aerospace Engineering was

also added, giving the resulting team representation from all undergraduate academic levels. Five freshmen and five sophomores brought the team size to thirty students. For the first time since beginning the SUCCEED sponsored project in Vertically Integrated Design a design team existed with students from all undergraduate academic levels and with representation from three different majors. The originally intended vertical integration aspect of the program has been very successful and will definitely be continued, something which can be done without outside financial support. The multidisciplinary (horizontal integration) aspect of the program, which was secondary to vertical integration as an original project goal, has proved to be more important to the students' preparation for the workplace than participation in a design process as a freshman. The continuation of the multidisciplinary aspect of the design program is now a primary goal of future project planning. An important factor in these plans will be the ability to offer an international teamwork component in the program.

Multidisciplinary expansion

In the 1997/1998 year the multi-disciplinary aspect of the experiment has been expanded, adding a few Materials Engineering and Electrical Engineering seniors to the mix while keeping the total number of participants constant. The team had five AE seniors, 3 ME seniors, 3 ISE seniors, 2 MSE seniors, 1 EE senior, and 1 student who was both a senior in ME and a junior in EE. Again there were 5 AE juniors and 5 AE sophomores and 5 General Engineering freshmen were added in the Spring semester.

The international component of the 1997–1998 experiment also changed in concept with the goal of running a parallel program of design instruction at both the American school and the European school. Arrangements were made during the summer with Professor Lloyd Jenkinson, the aerospace design instructor at Loughborough University in England, for his students and the Virginia Tech students to work in parallel on a similar airplane design project. The Virginia Tech team visited Loughborough University over Thanksgiving and worked with the design students there on a design of a fully autonomous general aviation aircraft. Through internet web sites and e-mail the students from both countries were able to communicate easily during the remainder of the academic year and to share ideas even while creating somewhat different solutions to a common design problem. In an important expansion of the program the students and faculty from Loughborough University were able to visit Virginia Tech in the Spring of 1998. For the first time in the international design experiment a full exchange of visits had been made, allowing a complete, year long collaboration on the design process.

The goal in future years is to create a design program which will allow collaborative design teaching/learning at Virginia Tech and cooperating European or Asian universities accompanied by an exchange of visits during the academic year. Funding from industrial sponsors has made this possible in the 1998/1999 academic year and Virginia Tech and Loughborough University are continuing their exchange of visits and enhancing the program with the establishment of truly international design teams. Three teams composed of students from both universities are working on two different aircraft design projects. Discussions have begun with several Asian universities regarding the establishment of similar programs in future years.

ADMINISTRATIVE BARRIERS

Perhaps the most difficult problem in creating a truly multidisciplinary design course is getting beyond the isolationist views of most academic departmental bureaucracies. As reported in a section above, it was somewhat surprising to learn that most engineering departments at Virginia Tech did not have a true capstone design course, at least of the type found in most aerospace engineering departments, and that, even in the departments with such a course, team projects involving the design of major, complex systems like an aircraft were not the norm. Both the ME and the ISE departments required team designs in their senior design courses and both had a two-semester sequence, hence, their choice as partners in the initial multidisciplinary design experiment. The ME Department at Virginia Tech has a two-course design sequence but students are not required to actually begin a design project until the second semester and that project is usually related to design of some component of a system. ME students could begin a project in the first semester by enrolling in an optional course. The ISE Department requires its student teams to work with an industrial or academic research group which has posed a design problem for that group.

In order to simplify the 'book keeping' for the departments involved it was agreed that students would enroll in the normal design course for their major. Course grades for participating students would then be processed through their own department's design professor. This resulted in some problems for some of the students involved during the first year of the multidisciplinary experiment.

While the ME design professor had no reservations about allowing the AE design professor in charge of the program to assign final course grades for participating ME students, the ISE design professor retained the right of grade determination for his department's participants. He also asked that the ISE students work with an ISE professor as a project advisor. This created problems in that while the other students had only to satisfy the

demands of one professor, the ISE participants had to meet the requirements of three faculty; the general aviation project advisor, their ISE faculty advisor, and the ISE design professor. Inevitably problems arose if the project advisor recommended a grade and it was changed by the design professor. Other problems resulted when the ISE advisors or design professors wanted written reports at times that did not mesh with the report schedule for the general aviation team or when the ISE students were asked to produce something which was not required of others in the GA team. These problems were very counterproductive to the efforts to build a unified team where all participants felt free to work together. The ISE students felt that they were being required to do work that was not required of others on the team and that they were at a distinct disadvantage compared to other ISE seniors in the grading process. This also prevented the ISE students from feeling free to move within the overall team from one subgroup to another because of the need to stay with the other ISE students on the portion of the project related to the interest of their ISE faculty advisor.

These problems came to a head early in the project's second semester, and after a meeting of all involved faculty and students with the assistant dean in charge of the international program, it was agreed that grading and project assignments would be solely the responsibility of the general aviation project advisor.

The second year of the multidisciplinary program worked well administratively since most of the problems which surfaced in the previous year had been solved. The addition of students from two new majors, EE and MSE, in the project's third year resulted in the reintroduction of some of these same problems. It seems both that the EE and MSE departments are used to having their students do individual design projects which are more like undergraduate research projects than design. This results in these students being required to do individual research reports in addition to their part of the design teams reports and presentations. Hence, yet another departmental barrier needs to be pushed aside to make the multidisciplinary project work.

STUDENT PERCEPTION BARRIERS

The major challenge remaining was that of breaking down the barriers among the students themselves. This is less of a problem for the ME and AE students who have similar academic curricula. The Industrial Engineering students, on the other hand, have a very different curriculum with completely different emphases than the AE or ME curricula. This results in considerable apprehension on behalf of the IE students at the beginning of the project. There seems to be a real concern among the AE and ME students that even the simplest engineering theories will be beyond the comprehension of the IE's, a fear which is shared by the IE's, who even go so far as to refer to themselves as the 'Imaginary Engineers'. The result can be a rapid compartmentalization of team effort, with the students in each major carving off their own piece of the work and hoping that they won't really have to interact too much with the others.

In the first two years of the experimental multidisciplinary program, despite the use of classic team building exercises, lectures in team management, and assignments given to smaller teams composed of students from all three majors, it was obvious that the creation of a real team spirit of full co-operation was very slow to evolve. In both years the students did not really gel into a fully functioning team until they found themselves in a strange country on their own. Unlike in a company where the employees, regardless of previous academic major, all view themselves first as employees of that specific corporation, students tend to identify themselves by academic major and getting beyond this view of self is not an easy task. When in a foreign setting, however, they find it easy to develop a group identity that transcends their departmental identities.

Hence, there are two very strong motivations for seeking the means to continue the international aspects of this program. The first is still that of giving participating engineering students the opportunity to work with their counterparts in another country on a design project of mutual interest. This provides an incomparable opportunity to experience first hand the importance and complexity of international co-operation on engineering projects. The second is the benefit of this activity in rapidly bringing a group of students with diverse backgrounds together into a cohesive design team.

It was interesting to see the result of the 1997/1998 experiment in terms of the effect of the trip abroad on team building. This trip was to England where there was little or no language barrier but there was still the factor of being a group out of its usual cultural and social context. This trip appeared to have the same team building results as previous trips to France.

CONCLUSIONS

The capstone design project described above has evolved from one emphasizing the inclusion of freshmen in a traditional senior design course, to one of a completely vertical and horizontal and international integrated design course. There are advantages to be found in each step in the integration process as well as difficulties associated with their implementation.

Vertical integration

This program began by placing one or two freshman engineering students into a traditional AE or ME senior design team. This has worked very well for the past eight years and a comprehensive survey recently conducted of all students who participated as freshmen showed that there was a high level of enthusiasm for the program. Regardless of the current academic level of the former participants, they cited the program's value in enhancing their preparation for later coursework. Sophomores noted that it helped them better appreciate the value of courses like Statics and Dynamics and to consequently do better in those courses. Juniors said that the experience helped them to understand where their first 'in-major' courses were leading. Seniors cited the experiment's value in preparing them for their own capstone design course. Students at all levels, including those who had graduated, commented on the value of the early teamwork experience, noting that this type of semester-long team participation was much more valuable than that found in typical mini design team projects found in several courses.

There has been only one real problem with the freshman participation part of the experiment and that stemmed from the original concept of centering freshman involvement around a CAD assignment. When the program began Virginia Tech freshmen were using a fairly unsophisticated CAD software with a very rapid learning curve as part of their introductory engineering classes. Since then, at the insistence of many who wanted the freshmen to have a more comprehensive CAD program, the CAD package used has grown in both capability and complexity and the rate at which the students learn to perform even simple CAD tasks has slowed considerably. This has resulted in a continuing decline in the freshmen's ability to make significant contributions to the CAD requirements of the design project.

The addition of sophomores and juniors to the vertical mix in the 1996/1997 academic year worked well. The juniors often proved just as able to accomplish tasks in the design process as the seniors and, in fact, a couple of the juniors became leaders of groups that included seniors. The fact that the AE juniors took a comprehensive course in Aircraft Performance in the sophomore year allows them to come into the team at the first of the junior year with competence in the area of airplane performance and their confidence and competence builds as they go through their junior program of aerodynamics, structures, and flight mechanics courses. Several of the juniors became very effective leaders within the design team.

The sophomores entered the team in the second semester of the project along with the freshmen. Their main task was to build a wind tunnel model of the design for testing and evaluation. All of the sophomores were AE students taking the Aircraft Performance course. The sophomores worked well with the team and eventually contributed significantly to the team effort; however, delays in the definition of the final form of the aircraft design resulted in frustration for the sophomores as they waited to start the model building process. In the second year of using sophomores in the project, attempts were made to define the model shape earlier and to find other meaningful tasks for this group of students early in the semester.

The current year has brought significant changes in the first year program for engineering students at Virginia Tech. This will lead to a reassessment of participation of freshmen in this program. Particular emphasis will be put on the CAD and drawing capability taught to the freshmen in a much revised introductory engineering course. The author's current thinking is that some mixture of freshmen and sophomores can be successfully utilized in the project in the future.

Horizontal integration

The formation of a multidisciplinary senior level design team was almost accidental in a project which began looking only at vertical integration of students; yet, it has, without question, been the most satisfying part of the experiment. Begun in response to the NASA/FAA General Aviation Design Competition, it has proven very successful in the eyes of the participating seniors and to industry observers. At the end of the first year experiment with the multidisciplinary team the vast majority of the seniors on the team recommended that the use of seniors from different majors on a single team be continued and, after two years of doing this there are no plans to go back to a single major design team. As mentioned earlier, the 1997 team had students from five different engineering majors. Consideration will be given in future years to adding non-engineering majors to the mix.

The addition of each new major brings a renewal of the problem of dealing with departmental hang-ups over administrative and grading matters, however, it is worth this hassle to create a truly multidisciplinary design experience.

One interesting, real-world aspect of having such a mix adds to the design team organizational matrix is having to work around scheduling problems which come from having students from different majors and inherently different class schedules. The students in this program thus far have been able to solve these problems and work very well together.

It should be mentioned that the ability to use the Internet as a means of communication and as an organizational tool is invaluable. All Virginia Tech engineering students have personal computers with e-mail and Internet access. The creation of an e-mail list, if properly used and not filled with inane messages, can simplify communication for this size of design team and the creation of a web page through which all design drawings, reports,

and any other material can be accessed is an asset beyond value.

International integration

As mentioned above, the international portion of this experiment was almost accidental in origin. It has, however, been very valuable in generating student interest in team participation, in unifying the team, and in giving the students involved a clearer picture of the importance and complexity of the international marketplace. It has been relatively easy to arrange visits to three European schools and future plans are to work with Asian schools as well. In each case thus far the Virginia Tech team has covered its own travel expenses with the exception of housing, which has been provided by the host school, usually in unused dormitory space. The cost per student has been less than $1000 and this has been, thus far, paid through a grant of some type. There is reason to believe that future year's programs will be partially funded from industry grants. One suspects that, in most cases, students or their families would be willing to pay a nominal portion of the cost if needed.

With the continuing increase in the need for international partnerships in the aerospace industry, graduates with experience working in multidisciplinary teams and on design projects involving international collaboration should find themselves having added value to prospective employers. At Virginia Tech we intend to provide this type of graduate to our partners in industry.

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