Undergraduate Research Participation in the Experimental Aerodynamics Group

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Abstract

In the 1980s, the idea of faculty spending time to guide undergraduates in research projects was still considered to be rather risky in the traditions of the tenure track. This paper discusses the crucial role played by undergraduates in the research programs of the Experimental Aerodynamics Group at the School of Aerospace Engineering. Since 1985, roughly 90 students have participated in our program. About 50% have worked with us for more than a year, and a large majority have gone on to graduate school. Current participation averages 10 students at any given time. This paper summarizes experience in this program. Various ways in which undergraduates participate are summarized in the following categories: Research team members, Special Problems courses, Team projects / competitions, undergraduate research internships, and summer internships, as well as experience with high school students on summer assignment. General policies, evaluation criteria, programs metrics and lessons learned are summarized. The importance of recognizing individual preferences and talents is indicated, as well as the challenges and rewards of conducting programs with a broad range of participant interests. It is emphatically true that undergraduate participation is an absolutely vital "raison d'etre" of this university research group.

I. Introduction

In this paper, the evolution of undergraduate (UG) participation an experimental research group is discussed. Starting as a rarity in the 1970s and 80s, undergraduate participation has become prevalent today. The paper starts with a summary of peceived constraints, and the logic that enabled their circumvention. It then presents various mechanisms used to enable UGs to participate, and compares their features. The dynamics of team environments are then considered, in the context of the learning curve which faces UGs in research. Mechanisms of recruitment and advertisement are then discussed. The impact of UG participation is presented using several examples, projects uniquely enabled by UG participation are showcased.

Constraints and counter-arguments

In the 1980s, the idea of faculty spending time to guide undergraduates in research projects was still considered to be rather risky in the traditions of the tenure track. Many difficulties were cited. There was an abundance of anecdotal evidence for each of these obstacles. Few if any examples of sustained success with UG participation in research could be presented. In this environment, it was illuminating to compare the perceived obstacles against some of the realities of the graduate research program.

Table 1: Traditional obstacles to guiding undergraduates in research, and counter-arguments based on realities in graduate research programs

	Constraint	Counter-argument
1	Undergraduates have little time for participating in research projects, since they take full 17-21 credit-hour schedules.	Graduate students in the first year were often not productive in research, lacking any experience of doing research.
2	Undergraduates rarely stay long enough on a project to get the research to a point where refereed publications can be generated.	The attrition rate of graduate students at the end (or even before the end) of the first year, was roughly 50 to 75% of the graduate class each year.
3	Their level of technical maturity is not adequate to do credible research at a professional level.	In the cases of 75% of 1st-year graduate students, the level of intellectual maturity was not reaching that which would allow credible research.
4	Their technical background is inadequate to enable them to join research projects and understand the issues: the learning curve is too steep	The operation of modern experimental facilities and diagnostic systems requires that a graduate student have at least several months of experience before s(he) could be allowed to proceed unsupervised for safety.
5	Time spent in advising / guiding undergraduates is much more profitably spent guiding graduate students, since that is counted as part of the Promotion/ Tenure criteria.	Items 1- 3 above indicate that time spent in guiding poorly-prepared and unproductive graduate students, is less productive than time spent guiding enthusiastic undergraduates. Undergraduate assistants who stay on to graduate school have a stellar record of completing PhDs.
6	Undergraduate assistantships do not gain the traditional support enjoyed by graduate assistantships	The advisor must find other reasons to justify recruiting undergraduates: trying to change attitudes fossilized over decades is futile.

As long as a healthy graduate program was also maintained, the “RPT” issue could be addressed through other means. The above indicates that the remaining obstacle to enlisting undergraduates was the perception (and reality) of lack of credit for undergraduate guidance. If clear benefits could be identified, this credit criterion could be ignored.

Sixteen years later, it is appropriate to confess, in order to not mislead young and eager faculty members, that some expectation of long-term recognition must have existed at that time. However, several changes in Administration and Institute Strategic Plans, membership in several “high-level” Committees, NSF proposals and lunches with disappointed junior faculty colleagues later, the truth remains that *ignoring* the credit criterion is still the right way to stay motivated. Spending time with undergraduates is seldom recognized in Reappoinment, Promotion, Tenure etc., and the best one can hope is that it is not held against oneself. It is still essential to have enough “Papers in Top-Tier Journals”, “Laudatory Letters from Top People in The Field”, and enough research funding, to be left alone to do what one believes to be really important.

II. Types of Work Arrangements

Since 1985, roughly 90 students have participated in the Experimental Aerodynamics Group's research program. About 50% have worked with us for more than a year, and a large majority have gone on to graduate school. Current participation averages 10 students at any given time. The experience gained is summarized in the following categories:

1. Summer internships
2. Undergrad research internships
3. Special Problems
4. Team projects / competitions
5. Research team members

II-1. *Summer Internships*

Each summer, one or two of our own students ask to work a full 30 to 40 hours per week, taking at most one class. These positions require substantial funds, so we can accommodate only one or two. In addition, we get an average of 1 student every 2 years paid by some other source, who works with us through the summer. Very positive examples: Physics student from Spartanburg College, Summers '92 and 93. Student from French university system, on practical training assignment. Typically, these arrangements work best when the student has family or other support for staying in the area during the summer. Difficulties arose in another case where a student with relatives 90 miles away got discouraged by the highway commute to our location very quickly. In the case of summer internships, a report is generally produced by the student at the end of the summer (in the case of external students). However, no grades or course credit are provided. Local students who worked as summer interns generally have gone on to become PhD candidates.

II-2. *Undergraduate Research Internships*

Students in our group have won several of the internships awarded by the Institute's Graduate Office, and corporate internships such as the United Technologies Pratt&Whitney Engine Company internship. These are based on a brief proposal submitted by each student with the guidance of the professor. In some cases these well-publicized opportunities have served as recruiting tools: students find out from classmates about professors who are likely to serve as project guides, and thus find out about the larger opportunities in the research group. As discussed later, such students generally join the research team and work well beyond the parameters of the internship. Internships generally include formal presentations and interim reports to the internship program; yet these are generally at a relatively simple level. Generally, the work scope expected of these internships is less than that done by these students in the course of their regular assistantships, so the URIs are primarily a source to help us hire more students into assistantships, and augment the available resources.

A special case of internships is that of the NASA "SHARP" high school interns, recruited through the NASA Georgia Space Grant office. For the past two years, we have received a total of five high-schoolers, selected nationally by NASA, to work with us for 8 weeks of the summer. These are of course stellar students, who are quickly given as much responsibility as they can take. The supervision levels for such students has to be different than for undergraduates because of their youth. Presentations and reports developed by these students provide a unique perspective on the research environment, as well as excellent benchmarking information on how other research teams across the campus operate. Other local high school students have also occasionally worked with us as interns. Example projects are given in Table 2.

Table 2: Projects assigned to high school participants in the NASA SHARP program at the EAG, 1999-2000.

Project	Role of high school student
Exploration of inverse-morphing transformations for image processing	Student explored available products for integrating morphing algorithms into image-processing programs; contacted industry sources.
Performance calibration of an optical Speckle correlation wind speed sensor	Student worked with PhD candidate who was developing the sensor.
Development of a multibladed rotor system	Two students worked as a team with PhD candidates, handling product-search functions and participating in decision-making for system acquisition.
Measurement system for vortex tracking	Two students worked as a team to use a program developed by our group.
Business Plan for the “Inter Planetary Shipping Company” (IPS), a Space-based business with suppliers, facilities and customers all beyond Earth	Two students worked as a team to plan the general parameters of the company and develop a web page.
Project Document planning and preparation for sounding-rocket experiments using Acoustic Shaping	Two students worked as a team to collect information from the members of a larger student team, and start the central reference document for an upcoming off-site experimental project.

II-3. *Special Problems (AE4900-01-02)*

Traditionally, this was the primary mechanism for undergraduate participation in research [1-7], being modeled on a graduate Special Problem format. These are taken for elective credit (hours ranging from 2 to 4 semester hours). As the curriculum constraints have changed over the years, so has the attractiveness and feasibility of these. AE490x projects are used to give credit to rising juniors /seniors, generally in individual projects. These efforts have to be substantial in scope to get good grades. Generally, these are tailored to the student’s expressed interests. Examples are given in Table 3.

Table 3: Examples of topics for senior Special Problem projects.

Topic	Where the student went later
“Supersonic shear layers”	Engine Manufacturer; PhD program.
“Propulsion options for interstellar travel. ”	Astrophysics PhD program
“Study of a human-powered helicopter”	BSAE, specialized in materials
“Magnetic bearings for the Space Shuttle Main Engine cryogenic turbopump”	Current project
“Design exploration of an electromagnetic launcher on the lunar surface”	Current project.
“Cost estimation for a Mars–Earth Cycler Spaceship Using Lunar-Derived Material”	Current project.

II-4. *Team Projects (AE2900-01-02, AE3900-01-02)*
These are taken for elective credit (hours ranging from 1 to 3 semester hours). As the curriculum constraints have changed over the years, so has the attractiveness and feasibility of these. In 1987, a special section of the Design course was created to accommodate students participating in the AIAA Engine Design competition. In more recent times, several design competitions have interested students and faculty, leading to the creation of a course-credit mechanism called "Team Project Competition", with credit available at different levels depending on the level of the student participating. Thus it is recognized that students working on the same project may have very different academic backgrounds, and expected contribution levels. In 1999-2000, courses numbered AE290x and AE390x are used to give credit to students participating in team projects. Examples in our group are:

- Microgravity Flight tests [11,14,15,16] in 1997,98,99, 2001.
- "NASA Means Business" team competition [17,18,19], in 1999, 2000 and 2001.

Here, students develop individual reports on their assigned portions of the project, in the context of the overall project.

II-5. *Research team members*
This is the most common and preferred mode of participation [8-10,12,13,20,21]: a student walks into the advisor's office and asks about working in the labs. These students are paid, with hourly rates depending on level in the academic program. Typically, students work only an average of 5 or 6 hours per week, with the number of hours varying widely between students, weeks of the semester, and curricular demands. Each student is assigned one specific problem where s(he) is the team leader, but is also asked to work with all other teams as needed. The specific problem may run across years, and generally does. Examples: 1) Develop multimedia material from flow visualization video tapes, to be used in modernizing courses (NSF project); 2) Extract vortex strength from cross-flow image pairs (Army / NASA projects), 3) develop laser sheet imaging techniques, 4)write JAVA user interface for an Air Force computer program, 5) design a 3-D wind-driven manipulator. In each case, there is a PhD candidate assigned to "support" the project, who needs the results eventually.

III. Team dynamics and the Learning Curve

The most often-cited superstition ("superstition": a fear/belief based on ignorance) of faculty regarding UG research participation is that the students face a learning curve which is too steep to result in useful, professional-quality products. Extreme examples have been encountered, where faculty who do not participate in undergraduate guidance have obstructed undergraduate assistants doing work for school projects.

Such fears are not uncommon among faculty whose experience of undergraduates is limited to the view across the traditional lecture hall. The opportunity to work in a team with support available as needed, and experiment until successful, can unleash the tremendous potential of many students in areas little suspected by those who lecture them in the traditional courses. The team dynamic is totally nonlinear, and is hence very unpredictable beyond a very basic level. To realize the true benefits of this nonlinearity, students must be given an environment where there are some routine tasks which they can perform to gain confidence in their own worth, but beyond that, the students have freedom to innovate and contribute to the projects of all other students.

Typically, in the EAG, new undergraduate recruits work with a senior PhD candidate at the beginning. Within a couple of weeks, most such students become independent, reporting as project leaders at the weekly research meetings. Beyond this, students generally take on several assignments in parallel, so that they can always find something to do when they have time. The graduate students themselves are independent workers, so they do not wait very long for undergrads to arrive in the lab and help them. Once this aspect is realized, the undergrads evidently learn to work in a complementary manner with the graduate students.

IV. Discussion

IV.1 *Crosss-disciplinary impact*

Traditionally, faculty members are hired after a PhD and/or industry/research experience on "hot" topics of research where they can find funding. Their careers for several years thereafter are mostly dominated by the pressures to generate external funding and the peer recognition required to get more funding and keep their jobs. Then comes a "sabbatical" or perhaps summer appointments to outside organizations where they might gain new perspectives and new funding links, enabling a broadening of their areas of interest.

Working closely with undergraduates offers much more exciting alternatives. An extremely important aspect of hiring undergraduates into research teams is the potential for cross-disciplinary interaction and innovation. Briefly, the undergrads tend to view their advisor more or less as they view parents: Old and perhaps even likeable, but not necessarily very well-informed in the latest technology, unlike their teachers in classes, or their friends' bosses in their Co-Op jobs, or the people they meet at Conferences or Career Fairs. The result is that they freely discuss their projects with their teachers and friends, and bring back insights from various disciplines. Thus, for example, the undergraduate-initiated project on Acoustic Shaping caused some participants, 3 years into the project, to discover that their Physics teachers knew all about acoustics; this led them eventually to get (free) help from experts in Electrical Engineering to miniaturize their system. They also initiated contacts with several parts of NASA, which have since expanded into much deeper research interactions.

Professors across campus, as well as people in industry and research organizations, are very generous with their time and ideas to help undergraduates; far more than they would be if the requests came from their professors. Obviously, to encourage this, the students have to be given an environment where they know that everyone's ideas and contributions are gratefully acknowledged, and the main product is the joy of getting a project to work. Other examples of cross-disciplinary interactions abound in our projects, where undergrads bring new techniques and capabilities into projects, which the highly-focused graduate students might not have found.

Relating these findings back to the issue of *"what's in it for the tenure-track faculty member?"* one should note that undergraduate research team members can afford to find out that the idea which they have been exploring is a dead end, with no adverse consequences. Thus they can be let loose on projects where the technical risk is extremely high, far beyond that which a research advisor can tolerate on a PhD student's project. Since we are dealing with extremely bright and motivated individuals, the chances of success on even the most crazy-sounding projects is in fact quite high, assuming that the necessary course-corrections are applied to take advantage of the real opportunities found. For this to work, one must have an environment where students feel free to walk into one's office any time and discuss what appears to be total failure. The nature of research is such that, simply by thinking of ways to see something to salvage from a failure, under the pressure of sitting across from a student who is feeling down, one *very often* finds an unexpected direction to new success.

IV.2 *Advertisement*

Surprisingly, conscious efforts to advertise undergraduate work opportunities have brought only mediocre results, while word-of-mouth advertising between students has brought excellent results. The reason for this may be that students view the research participation decision as a personal and unique one, not to be taken as the result of a resume-mailing, but as a result of face-to-face discussion with the professor. Word-of-mouth advertisement appears to be effective in identifying research groups where such opportunities might be found. It is also true in many cases that undergraduates pay no attention to notices posted on bulletin boards, or to mass mailings or e-mails.

IV.3 *Projects enabled*

In 15 years, we can identify several projects which initially originated as undergraduate ideas. A detailed discussion of these is beyond the scope of this paper; briefly, what occurs is that an undergraduate takes interest in exploring what might seem like a wild idea, and gets it to the point where the critical issues can be clearly identified. This then leads to a focused graduate-level project. One example is the use of laser sheet videography to track vortices in the wake of helicopter rotors: the first experiments were performed in 1985 as part of an undergraduate effort. Work on microgravity acoustic shaping was started entirely by undergraduates in 1996; today this work has blossomed into a broad-ranging study of how to develop a space-based economy, involving students at all levels, and 3 universities. Exploratory experiments on a flapping wing, with flow at high reduced-frequency, high amplitude and low Reynolds number, were started by a team of two freshmen. This has led to a PhD program, now nearing completion.

IV.4 *Learning types & Evolution in Student Habits*

Observing undergraduate participants in research, especially in their first few weeks with the research group, is an interesting experience in viewing different learner types and study habits (besides social interaction styles). The procedure manuals in research labs are never perfectly complete: new things are always being tried. The "default" method for learning skills is to "follow a PhD candidate around". Beyond this, students use various techniques. Some try to collect all available information and read everything to impress the professor by the end of Day One. To avoid depression, students are not allowed to go off for weeks in this mode, but are encouraged to start doing simple tasks on the first day. Some prefer very detailed directions on specific projects; others welcome the opportunity to participate in many projects. Over the years, students have become more independent in their "learning curve" process, partly because much of the needed start-up knowledge is available through web-based resources.

V. General Evaluation Criteria and Standards

V.1 Weekly progress reporting

In guiding undergraduates, it is *absolutely essential to insist* on progress reports every week. Such steady progress keeps students thinking about their projects, and serves to minimize the adverse effects of the undergraduate's usual inclination to procrastinate. It also removes the common fear of reporting "zero progress", which is the case in weeks when students have several midterm tests, assignments, etc. In our group, access to the professor is very easy (open-door office policy, e-mail access, and frequent discussions in the lab or hallways). However, written reports are still essential. Various methods have been tried in the past 15 years. In the 1980s, students were reluctant to deal with the computer: hence the reporting requirement was used to insist on computer-printed reports. Reports were expected to be ½ page or more. In the late 1990s, e-mailed reports were tried, but abandoned because they were ofen done in too much of a hurry, with insufficient thought. Further, hand-written reports were required instead of computer-generated reports, to encourage students to do more creative graphical explanations of phenomena. Recently, due to increasing pressures on the professor from other commitments, students have been asked to keep progress reports on internal web pages, with surprise inspections by the professor as the "threat". This appears to be a reasonably happy medium, as long as the frequent face-to-face discussions are still treasured.

A weekly research meeting has been a group tradition for many years; although this has become very difficult to arrange in recent years. In these meetings, students at all levels are asked to report, discuss and comment on the group's work. Comments from alumni who went to industry indicate that they used to find the research meetings in the university to be very fast-paced and "stimulating" (or stressful, depending on the interpretation of that comment).

V.2 Co-authorship

In our group, the policy on co-authorship is that students are included as co-authors on professional-level papers where *justifiable*. This is different from some professor's view of co-authorship as something that has to be "earned" by doing all the work, with the professor's own name going on wherever justifiable. The superstitions about the precise order of authorship have also been discarded long-since, and are not missed. As seen in Table 4, 42% of research assistants have become co-authors, some several times. The percentage has been rising in recent years as students join earlier, stay longer and handle more responsibility with the research group. It is interesting to note that only 10% of Special Problem students authored papers resulting from that work. This is slightly misleading, since some of the early Special Problems students went on to join our research group as graduate students, and then of course they co-authored several papers. However, a 1-Quarter Special Problem is generally too short to result in a professional-level publication, and an isolated Special Problem experience does not give the student the same team exposure as a research assistant position.

V.3 Continuous guidance preferred to end-of-term grading as evaluation policy.

As mentioned before, continuous guidance through weekly reports and meetings (and usually more frequent office discussions) is used to achieve results, as opposed to end-of-quarter reports and grading.

V.4 Undergrads encouraged to assume more responsibility ASAP.
Motivation levels of students are increased by asking them to take responsibility for getting projects done. While there is an informal hierarchy in lab decision-making (PhD candidates can overrule undergrads when needed), undergrads are informed that they are the project *leaders*, and hence must do their own thinking rather than look to graduate students for constant orders.

V.5 Graduate students encouraged to mentor the undergrads.
The graduate students in the group are asked to take over as much of the mentoring of undergrads as possible. They are also asked not to treat the undergraduates as assistants, but as teammates. This rarely poses difficulty.

Table 4: Statistics on performance of undergraduates who did Special Problems or worked as research assistants in the EAG, 1985-2000. Current students are not included in the totals.

	Special Problem	Research Assistant
Left AE/GT before graduation	N/A	19%
Went to industry	23%	25%
Co-Op / external assignment	16%	58%
Joined grad. school, GT	42%	33%
Joined grad. school, elsewhere	35%	22%
Co-authored professional papers	10%	42%
Worked more than 1 school yr	N/A	50%

V.6 Metrics
Some metrics to assess the performance of this group might be:

1. Development of students (continuous evaluation through weekly reports, levels of responsibility assumed, etc.
2. Success of students in what they want to do next; i.e., Co-op jobs, graduate school, full-time jobs.
3. Undergraduate co-authorship of professional-level papers and reports. These are listed in the Bibliography.
4. Performance of teams in competitions: where appropriate, undergraduate teams have been encouraged to participate in national competitions. To-date, they have thrice won places in the NASA Reduced Gravity Flight Test program, and thrice been selected into the NASA Means Business program to develop strategic plans for the Space program, along with teams from the best *business* and engineering schools in the nation.

VI. Summary of Observations

- As seen from Table 4, many students have used this experience as a springboard to external jobs such as Co-Ops and Boeing summer internships. In the past few years, most of those who took Co-Op jobs have asked to keep working with us in their School terms, and some locally-based Co-ops have continued to contribute (but not get paid) during their Co-op terms out of interest in their projects.

- The success rate with such experiences has grown from about 50% in the early '90s to over 75% in recent years, but we still find some students who cannot adjust to the idea of working steadily and managing their hours. As the professor's life becomes busier, this is the aspect where time to turn a student around is simply not available any more.
- The ethics of the students in charging hours have been extremely impressive: no one has ever tried to overcharge. The usual problem is that the most efficient students charge the fewest hours.
- The weekly reporting requirement poses the greatest difficulty, and is the greatest differentiator between students.
- The incidence of interpersonal conflicts requiring the advisor's intervention has been extremely rare, and those few difficulties never led to students being asked to leave.
- Some guidance of advisor needed for undergrads to work with graduate students and other personnel. Grad students generally take cue from the advisor on how to deal with undergrads, and discuss this frequently and informally.
- Funding for such students has come primarily from research projects. Interest from the Administration is almost without exception limited to pious words, and thus this expectation must be removed as a motivating factor, because of its potential for demoralizing the professor.
- Demand for assistantship positions now exceeds the supply of interested faculty advisors.
- Recognition of such guidance in school workload has traditionally been a sore point.
- In general, such activity is not seen as important by school administrators unless it involves news media attention.
- Formal programs should minimize overhead demands on advisor's time: usually formal funded programs for undergraduate involvement take up far too much time on exhibitionism *("look how great we are: we actually CARE for undergraduates!!")* and leave too little to work in a meaningful manner with the students.

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VIII. Biography

Dr. Narayanan Komerath, Professor in AE and director of the John J. Harper wind tunnel, leads the Georgia Tech Experimental Aerodynamics Group (EAG). He has taught over 1600 AEs in 19 courses in the past 15 years. He is a principal researcher in the Rotorcraft Center of Excellence at Georgia Tech since its inception in 1982. He is an Associate Fellow of AIAA. He has won GT awards for Outstanding Graduate Student Development, Outstanding PhD thesis advisor, and Most Valuable Professor (GTAE Class of '91). EAG research projects have enjoyed the participation of nearly 100 undergraduates over the past 14 years. EAG is a leader in multidisciplinary team-oriented projects, including the Aerospace Digital Library Project at Georgia Tech: http: //www.adl.gatech.edu