Engineering Research at Predominately Undergraduate Institutions: Strategies and Pitfalls for the New Engineering Educator

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Abstract

This paper will discuss challenges and opportunities experienced by new engineering educators in conducting research at primarily undergraduate, nonresearch, teaching-oriented colleges and universities. Such institutions often contrast with flagship research institutions in regard to facilities, support, philosophy, and policies regarding research. However, research is still usually important for promotion, tenure, merit pay, and university image, thus often requiring the new professor to perform research with less-than-optimum resources and encouragement. Of course, a research record is critical to maintaining marketability and mobility.

Successful research programs can be built at such institutions. Careful selection of research niches is important to minimize cost and maximize relevance to institutional and regional concerns, particularly those of industries which can support applied research. Creative use of undergraduate research assistants is usually critical. Seed money programs aimed toward new faculty or faculty at undergraduate institutions, for example, the National Science Foundation Research in Undergraduate Institutions (RUI) Program, should be pursued by the new engineering educator at nonresearch universities. One's superiors must be made aware of all benefits, long term versus short term and intangible versus tangible, of a healthy research program not only to the professor but to the institution. One must make it easy for those holding the purse strings to say "yes" to reasonable, well thought-out requests for support of research and then provide frequent feedback as to its successes and value.

The paper will discuss these and other aspects of engineering research at such institutions, including ways to avoid possible mistakes. It will draw upon the author's experience in building a research program in semiconductor materials at a predominately undergraduate institution as he was climbing the ladder toward tenure, promotion, and reputation. It should provide "savvy" for the new engineering educator establishing research in such an environment.

I. Introduction

Research has historically been a component of the mission of universities and most colleges[1]. Emphasis on research has been heaviest at graduate degree - granting land grant or flagship institutions but mission statements; public relations material; promotion, tenure, and merit pay criteria; and even classroom objectives often loftily address the noble role of research even at predominately undergraduate, nonresearch institutions. However, the reality at such institutions is that research is often not considered nearly as important or supported as much by the administration or region as advertising implies, although a research record is usually critical to promotion, tenure, and merit raises and to one's gratification, reputation, and marketability in engineering[2,3].

This discrepancy motivates fundamental questions:
(1) Should research even be a part of the official mission and promotion, tenure, and merit raise criteria of such institutions?
(2) If so, what contributions can such entities realistically make to the state-of-the-art, especially in expensive equipment and facility-intensive high technology fields such as engineering and science?
(3) If the answers to (1) and (2) are positive, how can research of real quality be best facilitated with minimal resources and sporadic, unpredictable support?
(4) If the answers to (1) and (2) are negative, should faculty, particularly those new to academia, pursue research or be expected to do so?

Question (1) is frequently an area of debate. This paper will assume that the answer to Question (1) is "yes" and will address answers to Questions (2) - (4) with focus on new engineering educators starting research programs under the shadow of upcoming tenure and promotion decisions.

II. Research "Economics"

A pivotal factor in university support of research at nonresearch institutions is that of economics; that is, does it "pay" and to whom does it pay? The analysis involves profit and loss; that is, does the university take in more wealth than it expends, thus generating a "profit?" If actual dollars are received through external grants and contracts, the university can make money on a project through indirect overhead costs and the "profit" made by hiring a part-time instructor or graduate student to cover the researcher's courses at much reduced salaries and then pocketing the difference. However, more common is the requirement of significant matching funds or cost sharing by the university in the funding program's request-for-proposals (RFP), as a sign of commitment by the university. Although "in kind" non-cash matching can sometimes be used through waiver of indirect costs or internal granting of release time for research through reduced course loads, this still involves loss of revenue, fewer courses offered, or the cost of hiring replacement instructors with university funds. Cost sharing places a shadow over the enthusiasm and support of university administrators for research.

The situation is complicated because a university is not a "business" in the normal sense. Most universities do not exist to make money for owners, stockholders, or the state but primarily to provide education-related services to its constituency; its mission is to "give" rather than "get", assuming that it can do so without working in a deficit mode. Universities, thus act as clearinghouses and agents of transfer for what the author previously defined as "Academic Wealth"[4,5]. Any hard dollar profit on funded research is expected to ultimately be reinvested in improving the transfer of Academic Wealth, particularly education, to constituencies. Academic

Wealth can be anything that (1) has eventual direct value to students, community, or other constituents or (2) has potential to enhance the university's ability to generate or transfer other Academic Wealth. Actual dollars from external sources and popular educational innovations with potential to increase tuition dollars are two obvious examples but more indirect examples include publicity; enhanced relations with the region, industry, and state government; recruitment of students; dissemination of scholarly activities; and faculty development and morale, all of which can arise from research and benefit the university over the long run.

One difficulty that nonresearch universities have is figuring all examples of Academic Wealth into the balance sheet since most are difficult to quantify. Thus in calculating "profit," an institution might need to figure in an "Altruism Factor" ("A"):

"Profit" = (Quantifiable Benefits) - (Quantifiable Expenditures) + "A,"

where "A" takes into account all nonquantifiable, intangible advantages and rare disadvantages of a research project, particularly those enhancing student education. Of course, "A" cannot be assigned an actual number so decisions as to whether "A" is sufficient to justify administrative approval of a research proposal, when the profit without "A" would be insufficient, are made subjectively based upon reputation and record of the proposer, the university budget situation, potential publicity and educational value, and probability of project success and followup funds. In fairness, universities usually give the proposer the benefit of the doubt, but in lean financial times, may ignore "A" all together, revert to a hard dollar interpretation of profit and loss, and place faculty in a bind in playing the research game.

Support for and productivity arising from research funds are sigmoidal, "S" - shaped functions of both time and "dues" spent building a research program and both current and cumulative research support; that is, there exists a low slope "incubation" period, a region of maximum slope, and a saturation or stagnation region "past the point of diminishing returns." In the region of maximum slope one obtains maximum "return-on-investment"; that is, benefits such as additional administration support, grants and contracts, dissemination, publicity, equipment donations, and consulting projects vs. investment of time, resources and, stress. The best way to circumvent the decreasing slope in the saturation region is to "get things done through people" by transforming from researcher to manager and leveraging one's vision and expertise through other talented individuals. Although standard in Ph.D. - granting institutions with large faculty sizes and graduate students, to do this at smaller institutions is no small feat. The researcher, often a "lone ranger," must assess the benefits of research to himself, the university, clients or funding agencies, and society in light of what it costs in everything and realistically adjust one's goals and efforts for maximum rate of return and "Academic Balance"[5] in one's professional and personal life. Achievement of worthy research goals or "effectiveness" is still the bottom line but "efficiency" is also important given other time demands and opportunities that a new engineering educator experiences.

This maximum rate-of-return comes after an initial incubation period during which one is writing proposals, obtaining data, presenting and publishing papers, establishing a contact network, etc. Although slow and frustrating, these initial efforts act like compound interest and begin to rapidly bring in the fruits of one's labor once a critical mass in record and reputation is obtained.

That is, RESEARCH BEGETS RESEARCH quickly once critical mass is obtained. Thus, it is critical for the new engineering educator to be diligent, perseverant, resourceful, and bold to achieve critical mass in spite of frustrations, particularly at nonresearch institutions where there may not exist a complete or sympathetic research infrastructure.

III. Common Hindrances to Research at Undergraduate Institutions

Nonresearch or teaching-oriented institutes have characteristics that can hinder the scope or success of research efforts. This section discusses several of these.

Lack of graduate programs and advanced course work, laboratories, and equipment is a major limitation in leveraging the expertise and management of the professor. Although undergraduate research assistants can be utilized[6], their relative lack of knowledge, maturity, and commitment can be a hindrance. Also, there are often few, if any, faculty colleagues that share expertise and interest in one's particular narrow research field.

Personnel such as technicians, technical writers, and even secretaries needed to support research may be in short supply. Such deficiencies will have to be covered by the professor and student team, again placing an extra load on already overloaded personnel. The professor may have to utilize personal resources to expedite required services if not readily available on campus.

Such institutions tend to not have specialized equipment such as electron microscopes, advanced computing facilities, etc. commonplace at research institutions and even routine equipment such as meters, oscilloscopes, etc. may be in short supply or completely dedicated to instruction. Laboratory space is hard to come by; almost all space will have already been taken by senior faculty or dedicated to instruction. Thus the new professor may have to share space with a "mentor" who may not be overly sympathetic, or occupy a corner of an instructional laboratory. Specialized facilities such as fume hoods, air, gas, water, and electrical service may be nonexistent and expensive to obtain.

Library, audiovisual and multimedia resources tend to be less complete at such schools than at doctoral institutions. Although lack of journals and books in specialized fields can be circumvented by use of interlibrary loans, computer data bases, and relatively new on-line publications, these involve more delay, aggravation, and cost than having the documents on the shelf and available at a moment's notice.

Faculty sizes within a program may be small, say, a handful vs. scores as at large universities. This forces the faculty to handle a million different tasks such as advising, teaching, committees, research, consulting, laboratory instruction, equipment maintenance, public relations, recruitment, and paperwork without optimum division of labor and large blocks of unencumbered time to focus on research. Faculty at such schools tend to be "nickeled and dimed to death" in regard to demands on their time.

Full-time teaching loads are often 9-15 credit hours, including notorious 3 contact hour/1 credit hour laboratory courses with no graduate students to run them. Unless release time can be acquired, it is nearly impossible to build and sustain a competitive research program with such teaching loads. It is also uncommon for administrators at such schools to be technically oriented; a liberal arts perspective and background among top administrators are more common. Although usually operating with honorable motives and intentions, such individuals may not fully appreciate or understand the unique challenges, needs, and opportunities of education and research in engineering and science. This is especially true of expensive state-of-the-art equipment, publication charges, and external laboratory services.

Such institutions are often located in nonmetropolitan areas with few high-technology industries or other universities, and a relatively unenlightened constituency. This also limits opportunities for research, consulting, and technical assistance projects with and support from regional entities. It may also decrease the popularity of engineering and science majors and careers among incoming students and the pool from which to recruit research assistants.

In some cases, such schools are in the shadow of flagship research institutions and are not even "supposed to" be aspiring to be research institutions; this may be reflected in the state funding formula as well as general public perception. A misconception that high-level laboratory research and instruction cannot be performed at such schools may develop not only in the region or state but also in the university administration and faculty. Faculty may begin to feel that it’s not worth the effort. This is particularly prevalent with senior faculty who have attempted research earlier in their careers and been burned in the process; such individuals can dampen a new faculty member’s efforts. Some may not cooperate because of jealousy and threat to their "territory" while others may really think that they are doing the new guy a favor in setting them straight about the perceived uselessness of trying to start a research program.

The pace at such institutions tends to be slower than at large research institutions and the accountability often less. It is easy, even for researchers, to fall into a rut of not "pushing the envelope." They may slowly, and often without realizing it, fall behind in their field and lose prevalence and competitiveness. After ten years of writing 5+ papers, presentations, and proposals per year, why put themselves out when two will do? This attitude becomes particularly common after tenure and promotion to Professor unless other tangible rewards such as merit raises, release time, and influence motivate continuing hard effort. One may suddenly be shocked to find that he has lost competitiveness when a supposedly good proposal or paper is ripped apart by reviewers.

There is also a hesitancy of funding agencies, industry, and larger universities to fund or participate in collaborative projects with smaller institutions with no graduate programs, a limited record of research, and minimal laboratory capabilities. These entities may have had bad experiences in trying to do so in the past and also consider it not worth the effort in regards to payoff and probability of success. This stereotype can be a problem for a new engineering educator of ability and enthusiasm; that is, he simply may not be taken seriously.

IV. Tools of the Trade for Establishing Research at Nonresearch Institutions

To address such challenges, one must be resourceful and "do the best you can with what you’ve got" by creative and bold leveraging of available resources. The following describes a variety of strategies useful in this endeavor.

A new engineering educator must realize that he simply will not have time to sustain a research program over the long run without others to help him. This often translates into judicious use of talented undergraduate research assistants in the same vein as normally applies to graduate students. The author has used nearly fifty undergraduate assistants over the last seventeen years in his research in semiconductor materials [6, 7, 8]. Careful selection of the cream of the crop, followed by training, management, and motivation, will allow junior and senior engineering students to perform work as good or better than that of average Master degree candidates. Although not as desirable as a team of Ph.D. candidates, it does provide extra hands and hours to conduct research. The professor provides whatever advanced knowledge and skills are required to support the students' laboratory, computer, and library work.

Synergism can be obtained by involving researchers from different departments; this may be important because in small departments, there may not be any of one's colleagues interested in participating. By pooling personnel, equipment, and facilities of multiple departments, for example, electrical engineering with physics or chemistry in, say, semiconductor materials research, critical mass might be obtainable even if not so individually. This may require creative definition of the research problem so as to provide intersection with all parties' interests but it can pay dividends in productivity.

Hybrid, multidisciplinary fields provide an excellent venue for such collaborations. Examples such as materials science, environmental engineering, biotechnology, robotics, computer applications, and energy intersect multiple specialties in engineering, physical science, life science, health science, agriculture, etc. They also reflect what occurs in the industrial world and can attract industrial support. Since they overlap several standard fields, funding opportunities may be increased. For example, within the National Science Foundation, one can find requests-for-proposals in physics, chemistry, engineering, and materials science programs that overlap the field of semiconductor materials. This provides flexibility, multiple deadlines, and increased odds of funding.

One must pursue on-campus, regional, and state opportunities for funding since initial national competitiveness may be minimal. Often such programs, for example, the Arkansas State University Faculty Research Fund and the Arkansas Science and Technology Authority (ASTA) Basic Research and Applied Research programs, are primarily targeted toward new investigators or undergraduate institutions. Such programs allow one to turn the disadvantage of no graduate program into a relative advantage.

Federal programs that target undergraduate or nonresearch institutions should be utilized. NSF has several such programs, for example, the Research in Undergraduate Institutions (RUI) program that can coordinate with nearly all NSF divisions to provide funding for competitive proposals. NASA has the JOVE (JOint VEnture) program similarly targeted. Although rarely compromising criteria for funding, such programs often limit competition to similar schools vs. large research institutions or provide additional funds that the standard programs can use to fund proposals from nonresearch institutions. In either event, one's odds of being funded are improved.

Other programs target new faculty or faculty in states with historically meager research funding records. One excellent example of the former is the NSF Presidential Young Investigator Awards program, and standard examples of the second are EPSCoR (Experimental Program to Stimulate Competitive Research) programs of many Federal agencies. The latter program(s) are generally coordinated by the states but serve as conduits of federal dollars to researchers with potential to become nationally competitive.

Linking with industry is a powerful means to acquire research or development funding. Funding might come totally from the business, as with consulting, but another attractive strategy is to leverage the company's contribution with money from programs that target university-industry-government partnerships. For example, the Small Business Innovative Research (SBIR) programs of many federal agencies fund university - industry collaboration with potential for marketable innovations. The relatively new NSF GOALI (Grant Opportunities for Academic Liaison with Industry) program does the same thing. Even state programs may facilitate university - industry collaboration. For example, the Arkansas Science and Technology Authority Applied Research Program will match the industry's contribution 1:1 and even 2:1 if the industry is sufficiently small.

Research and consulting with industry are, however, not without challenges. First, industry is ultimately concerned with markets and profit and not necessarily in nobly contributing to the general knowledge. Since the time value of money and money value of time are critical to competitiveness and profit, schedule and budget constraints on joint projects with industry may be more stringent than is the norm in academia. This is particularly problematic is undergraduate institutions in which faculty may be overloaded with other duties and may simply not be capable of providing the intense, dedicated effort that industry expects from its own employees. The industrial expectations and deadlines may be difficult to meet.

Industry tends to be proprietary about what it has funded and may not allow the results of the research to be published or presented, as is so important to new faculty working toward tenure and promotion. Similarly, it may claim all intellectual property and patent rights to the work. This can lead to hard feelings with university administrators and attorneys since the university generally also wants a share of the intellectual property rights and any eventual royalties or income. In nonresearch institutions that have not previously been down this road, such problems can kill any long-term research relationship with the particular industry.

Industry tends to look at universities, particularly state tax-supported institutions, as it does a public library, that is, as a free or low cost source of assistance. University faculty and administrators rarely see it that way. The industry may expect the university to contribute to the project through use of facilities, equipment, and personnel for free or some token payment or donation. The university wants to make money on the deal. This can lead to disagreements about the details of funding and also sour a project.

The best way to circumvent these problems is very frank and complete communication early in the process, followed by written documentation, contractual if necessary. Budgets and fees, payment methods and schedules, work schedules and deadlines, deliverables and reports, intellectual property, dissemination, and other critical issues must be spelled out in black and white. Assuming anything on either side is a major mistake. The project must be carefully planned and thought-through to avoid misunderstandings. This process is usually mandated when a third party such as a government funding agency acts as a watchdog over the collaboration. It is worth the effort to bend over backwards to get to know industrial colleagues and their managers well and develop understanding, trust, and rapport so that communication, flexibility, and, if necessary, forgiveness can be maximized.

Government used equipment programs, for example that of the Department of Energy, are excellent sources for equipment on a first come-first serve basis; occasionally one can acquire a real jewel or large item if the first to put a claim on the item. Generally, the equipment is free except for shipping charges.

Another way that lack of specialized equipment can be circumvented is through other universities or commercial laboratories. Even if one does not have a formal research collaboration with another university, arrangements can generally be made to have measurements performed for minimal fees, particularly at schools in the state or region. Commercial laboratories are generally faster in turnaround time but expensive, often $100 - $300 per hour of measurement time. Another option is to rent the equipment but this is still usually expensive and provides equipment for only a limited time.

One of the best ways to "kick start" research is to link up with researchers of similar interests at larger research institutions within a region. This may require initiative and diplomacy on the part of the new guy; the burden of proving his and the institution's ability to contribute will probably be all his. Land grant-type universities sometimes "look down their noses" at other schools in the region and may require some convincing. Formal collaborative research programs within a state, for example, the NASA/Arkansas EPSCoR Program and the NASA/Arkansas Space Grant Consortium Collaborative Research Program, are two in which the author and Arkansas State University have formally collaborated with the University of Arkansas, both the Fayetteville and Little Rock campuses. Such programs catalyze the process by mandating involvement of multiple schools in a state-coordinated research program. Such projects have been made much more feasible by modern transportation and communication services such as overnight shipping, FAX, Internet, and e-mail.

New engineering researchers, particularly those isolated at small rural institutions, must develop contact networks at their own universities, regional and state institutions, industry, funding agencies, and state and federal research entities. These contacts are invaluable as references, outside consultants, advisory panel members, collaborators on joint proposals, suggested reviewers, sources of consulting projects, sources of inside information and opportunities for funding, sources of measurements, and other specialized services. The new professor should develop these contacts at regional conferences, short courses, state agency public forums, and meetings of professional societies.

Another excellent way to do this is to swap seminars; that is, present as many seminars as possible at other institutions, including industry, and invite their representatives to present seminars at one's institution. Offers or invitations can even be issued cold without previous interaction and based upon the potential host's or speaker's reputation. Spending a few hours with the individual will develop a rapport that can be tapped in the future. One must be friendly and diplomatic to avoid any poor first impression. Seminars presented must be of utmost quality and, for those hosted, all preparations, facilities, audiovisual equipment and refreshments must be perfect. This initial contact should be nurtured by occasional followup phone calls, sending "FYI" material, and flattering requests for advice.

There should be continuous nurturing and lobbying of the university administration to develop good will and emphasize the benefits of research to all participants. Every reasonable opportunity to advocate research should be used to educate administrators not fully sensitive to its value. This can be performed through frequent proposal submission, placing research equipment on periodic lists of needed equipment, strategic memoranda, and incorporation of research features into instruction. Opportunities to bring concrete revenue or resources to the university should be pursued; whenever possible, indirect costs should be included in proposals. As much as possible, the funding agency should fund faculty salary and fringe benefits so that the university can profit from the salary savings. Many funding programs require cost sharing but this should be handled creatively to minimize the real cost to the university and allow it to make a "profit" on some form of Academic Wealth.

Opportunities for publicity can often be created by nurturing relationships with the campus public relations office and the regional media followed by well-written press releases or phone calls. Publicity not only enhances the researcher's reputation but also makes the university and administrators look good, particularly when their names can be mentioned. Such publicity can lead to consulting projects with regional firms which, in turn, can lead to more extensive research and development projects. It also enhances one's general credibility and influence on-campus.

At the national and international level, similar results accrue from heavy and consistent, but optimally spaced in time, dissemination of research through journal publications and conference presentations. These are critical to becoming recognized in these broader arenas and further enhance credibility at the local and university level. They build the solid resume′ critical to being funded on proposals and provide a global perspective on research. Dissemination is usually the dominant factor in propelling one out of the incubation period into a period of high productivity and success vs. effort and time. The best ideas and research in the world are of little value if not communicated.

Similar recognition occurs through proposals reviewed by other academic experts in one's field and agency program managers. This benefit is in addition to the increased probability of funding produced by a proposal "blitz," assuming that all proposals all are of top quality.

Participation in multiple professional societies is important. Most societies have national and international meetings once or twice per year in major cities; these are excellent forums for presenting the results of research. Most have regional sections which hold their own conferences to provide opportunities for getting to know colleagues at closer regional schools. For example, at one time the author's research in semiconductor thin films was simultaneously supported by membership in the Institute of Electrical and Electronics Engineers, the Electrochemical Society, the American Physical Society, and the Materials Research Society and, to some extent, ASEE and the Arkansas Academy of Science. Although total yearly dues are expensive, multiple memberships multiply opportunities for presentations and publications and build a solid resume' quickly.

Participation on professional society committees and task forces rapidly propels one to prominence. Arranging, often by simply volunteering to the right people, to be a chair of a conference symposium produces similar results. Such positions generally go to more prominent researchers and promote a reputation as such even for a relatively new professor.

With all such strategies, it is critical that utmost attention be paid to quality, details, and professionalism. That is, when one is in second place one must try harder. First impressions run deep and the big boys sometimes are looking for any reason to discount any competitor from a smaller school. Sloppiness, incompleteness, "poor science," etc. are the kiss of death in the research game. Quality in both content and appearance must be extremely high.

Coursework can be synergistically coupled with research. For example, the author has all of his undergraduate research assistants take one credit hour of ENGR 4491 Special Problems in Engineering with a topic-specific subtitle every semester as part of the job requirement. The students write midterm and final reports on actual research, make biweekly presentations with audiovisuals to the research team, and support these with up-to-date literature. The course credit and grade further motivate good research. Furthermore, special problems or special topics-type courses can be used to offer new research-related lecture courses to small classes before or in place of adding them to the catalog as regular classes. The instruction provided in the lecture class can mutually complement the research.

When severe funding, equipment, or other constraints exist there are still high payoff opportunities for research and scholarly activity. Regional phenomena and concerns involving natural resources, agriculture, the environment, and even history can serve as avenues for research. Such studies may not be big international news but are excellent material for regional and state dissemination, including regional conferences of professional societies and state organizations such as the Arkansas Academy of Science.

Pure "scholarship," versus experimental research requiring equipment, supplies, and facilities, can also be undertaken through library and Internet resources, interviews and questionnaires, and site analyses. The results can be disseminated as review articles in general interest publications. Similarly, one can conduct educational research in curriculum, pedagogy, and assessment without research-grade instrumentation and facilities. These studies can be disseminated in numerous ways; for example, through ASEE conferences and journals such as Prism and Journal of Engineering Education and through educational wings of other societies, for example, the IEEE Education Society's Transactions on Education. Although not as prestigious and marketable as technical research, such work is valuable to its audience and does allow a professor otherwise blocked from experimental research to continue to be a scholar and build a resume′.

An even better way to circumvent lack of facilities and equipment is theoretical research or computer modeling and simulation. Nearly every professor now has a Pentium or 486 personal computer readily available. There are numerous powerful engineering and science computation and simulation software packages, for example, Mathematica, MATLAB, Mathcad and Maple, on the market at affordable prices. A capable professor can identify a topic rich in theoretical and simulation possibilities, for example, electromagnetics, fluid dynamics, or semiconductor phenomena, and, after study, commence modeling and computer simulation in focused areas without experimental equipment. Of course, it is better if modeling and simulation are supported by experimental verification but the literature is filled with results of modeling alone with the implication that others or future work will experimentally verify the results. This is considered acceptable if performed rigorously.

Similarly, to avoid the competition and pace associated with hot research fields, one can focus on exotic, just emerging, or highly focused fields and become a "guru" in them. Although initially lacking the glamour, funding potential, and industrial marketability as the hot fields, they do offer the opportunity to be "a big duck in a small puddle" and sometimes become the "grand old man" of a new field. For example, the author was one of only a handful of researchers worldwide concentrating on electrodeposition of semiconductor films, a field that emerged only in the late 1970's but through the 1980's, as the author was making contributions to and becoming well known in the field, became much more popular.

One with meager institutional resources can conduct experimental research at minimal cost by careful selection of "niches" with low capital equipment and supply costs. In the electrodeposition of semiconductor films, the equipment and supplies required to actually deposit the films are extremely low cost. Standard chemicals and glassware can be used and the 3-terminal potentiostats required for voltage control can be constructed in-house from operational amplifiers and standard electrical components. The real expense is in the characterization of the film properties but in the early days of the author's work, much of this was done off-campus in collaboration with other universities. Although somewhat limited, such niches offer potential for valuable, albeit focused, research.

V. Required Personal Characteristics

Last but not least among the tools of the trade for new engineering researchers from nonresearch institutions are personal characteristics. First, the new engineering researcher must have a real desire to build a research program and enjoy the benefits of such. Without this desire, one can not sustain the required commitment and perseverance to see one through the inevitable "no's," rejections, obstacles, and failures encountered when first starting out. Usually, this will couple with the professor enjoying research activities; this trait generally will have emerged in graduate school or earlier. In a sense, one should have "fun" in discovering new things about the universe and creation. If one did not enjoy research in graduate school, it's unlikely that one will become a real long-term researcher as a professor.

Perseverance is a must. One rarely will succeed with first attempts, particularly proposals, but one must try and try again through the incubation period. One must learn from mistakes and criticisms, particularly reviews of publications and proposals, assess what should be done next time, and roll with the punches. This takes a tough skin and one must not take rejections and criticisms personally, even if unfair. One must stay cool and logical and not let emotions sway thoughts, words, or actions. This usually requires already existent self-confidence. Mentors, chairs, and deans can help here by offering moral support.

Also needed are initiative and boldness. Unless the new professor can join an established group with a senior mentor, research success won't grow on trees or fall out of the clear blue. One must mix these with diplomacy, moderation, and humility, particularly when dealing with university administrators. When initiating ideas and requests, one must constantly justify their value to all parties and produce a concrete benefit to the university. Occasionally, one may even have to take a calculated risk if the potential payoff and its odds of success are sufficiently high; on the other hand, one should never be so daring so as to jeopardize one's job if things don't work out right.

Academic research is highly "political" [9, 10, 11]. To play in the big leagues, one must have good interpersonal skills, including those of negotiation, back scratching, socializing, and communication. For engineering and science types who often tend to be loners and introverted, these skills are not foregone conclusions but must be nurtured through practice. One should remember that human nature is based, in the final analysis, upon "what's in it for me." Even in noble and sacrificial activities there is some payoff for the giver. Requests and proposals need to be steeped in the benefit not only to the institution but also to the individuals whose support is needed; for example, a chair looks good when he has a highly productive faculty.

A sense of timing is critical. One should keep tabs on university, funding agency, and professional society budgets, priorities, activities, schedules, and deadlines and ascertain the best times to strike. Good proposals submitted at the wrong times can fail miserably and fair proposals submitted at the right time may succeed. For example, one doesn't ask for a major supply purchase out of departmental funds during the last month of the fiscal year, or send an equipment proposal with significant institutional cost sharing just after the state and university have announced a major revenue shortfall.

The flip side is that one must have already planned and prepared to strike with a rapid response time, often within hours or overnight. Often there will be a brief window of opportunity that will close as suddenly as it opened and one must "strike while the iron is hot." For example, during the last day of the fiscal year the chair may find that due to a minor miscalculation there are still several thousand dollars left in the supply account that must be spent, via requisitions, by "tomorrow." Those faculty that (1) are on-hand and (2) can prepare, within a few hours, a request list with vendors and prices will get their goodies. Requests-for-proposals from funding agencies may have brief open periods or imminent deadlines, or may have been misshuffled and get to the potential proposer only a few days before the deadline. He who can respond with lightning speed will succeed.

Time, personnel, and facilities management skills are important. A professor has a multitude of demands upon his time and the only way that research is going to be conducted is by squeezing every drop of value out of the time available and leveraging time with extra minds, eyes, and hands of student assistants and colleagues. Disorganization and waste spell failure in research.

Innovation, resourcefulness, and creativity are also important in idea generation, brainstorming, concept association, experiment design, and data analysis. One must look for multiple paths and solutions, some of which may be new or nonobvious. One must use the tools on hand or quickly obtain those required to get the job done. These characteristics are what separate the truly great researchers and thinkers of history from the average. So often, great strides in science and engineering have been made because one refused to be satisfied with the old way of doing things and brought together previously disjointed concepts to come up with startling innovations.

One must be flexible, adaptable, and even generous. In the early days of building a research program, one may have to work without adequate release time until external grants come. One may not receive recognition or merit pay for the initial hard work. One may even have to expend personal funds and, of course, much time to make critical purchases, obtain critical services, or travel to critical meetings if university or external support is not available and the need and potential payoff are great. For example, professional society dues and personal journal subscriptions must usually be paid by the professor himself. It's all an investment; a little blood, sweat, and tears in the early years will usually pay off handsomely later.

Continuing education, professional development, and ongoing productivity are important, particularly as the new engineering educator approaches middle age. After promotions and tenure, it's easy to fall into a rut of taking things easy. Although Academic Balance[5] is critical to an engineering educator, one must be careful to avoid stagnation, obsolescence, and the status quo. Given the rapid "half life" of 3-5 years for engineering knowledge, this obsolescence can sneak up upon an engineering professor not only in research but in all phases of the job, for example, computer techniques in instruction. One must keep up with the state-of-the-effort in his field if research proposals are to remain competitive. There is little worse in a proposal than in proposing something that someone else has already recently done.

Finally, one must occasionally step back and look at it all in perspective from various viewpoints. An academician must also see things from a commercial and public perspective. Research and related activities are not ends in themselves but means to a better society and a better standard of living. The funds for research come ultimately from somebody's pockets and, thus somebody is due benefits from such. This benefit can be focused and short term as with applied industrial research, or diverse and long term for society and posterity in general as with theoretical research, but in any event, research should be planned and conducted with potential contributions in mind. Although sometimes lost track of in the funding, promotion, tenure, and publication frenzy of modern academia, this contribution is the reason that research and scholarship have historically been major components of the mission of universities.

VI. Final Comments

The following are a few miscellaneous final thoughts that sum up and augment the previous discussion.

1. Those who enjoy research will find a way to do research in some manner. Those who do not enjoy it will usually find ways to minimize or avoid it, even as university faculty.

2. Universities can foster research by not only adequately and consistently rewarding it but also by doing all that they can to make it convenient, gratifying, and enjoyable for the faculty. Research is best facilitated by carrots rather than sticks through liberal and consistent motivation, reward, and recognition, rather than fear of not receiving promotion, tenure, or merit raises. It is also promoted by fostering an environment conducive to research, and by supporting consistent high quality, and not necessarily quantity, in research.

3. Research should always be, to some degree, an official part of the mission of all 4+ year colleges and universities, especially those with programs in rapidly changing technical fields of science and engineering.

4. Undergraduate and other small or nonresearch institutions can make significant contributions to the state-of-the-art by careful targeting of specific areas of relatively low cost but high potential payoff, and by collaborating with other entities to augment and pool resources.

5. Even in the face of negligible institutional support, individual faculty should pursue, to the extent realistically possible, research, scholarship, and related activities to facilitate personnel and professional development, academic survival, marketability, a better educational experience for their students, and potential benefit to their employers and society.

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