Participation of Undergraduates in Engineering Research: 
Evolving Paradigms over Three Decades of Change

Introduction:

Participation of undergraduates in research has received escalating attention over the last two decades as a “win-win” situation for students, faculty, and institutions. It serves as experiential- and service-learning enhancement of students’ total education and marketability, often within a multidisciplinary and honors context. Many institutions and government agencies have established infrastructures to support undergraduate research. However, the author has advocated and mentored undergraduate research for nearly three decades, starting when it wasn’t nearly as in-vogue as it is now. References 1.- 4. described his experience in conducting research in a purely undergraduate electrical engineering program in a historically teaching-oriented, master-level institution in which undergraduate utilization was critical due to absence of engineering graduate students.

This presentation will survey his long-term experience with undergraduate research in a semiconductor materials-oriented research program, and how student perspectives and expectations, and the management/mentoring paradigms involving such, have evolved significantly, for example, in relation to the advent of computer technology and the Internet. It will update the strategies presented in his 1985 paper with the tempering of 25 additional years of experience with opportunities and challenges of such. The audience, particularly faculty new to undergraduate research, should obtain a well-seasoned perspective of the issues, including specific recommendations, strategies, and pitfalls to avoid.

Background:

The author began establishing a research program shortly after commencing his academic career in 1982 at Arkansas State University in a new, purely undergraduate Bachelor of Science in Engineering (BSE) program with professional concentrations in civil, electrical, and mechanical engineering. This was at a university that historically had been strongly teaching-oriented, and had no doctoral-level programs. Since he was initially the only electrical engineer on the faculty, initial teaching loads were 12-13 semester credit hours, usually 4 different courses and a laboratory, on top of a heavy advising, service, and new course and laboratory development role. Thus, the overall workload was significant.

In spite of being at an institution where research expectations were secondary to teaching, the author not only recognized the importance of establishing a research program relative to promotion, tenure, merit pay, and professional creditability and mobility, but also sincerely desired to remain involved in research, as a follow-up to his graduate school research experience. The lack of engineering graduate students, as well as a minimal research infrastructure, made this challenging, so the author sought ways to creatively leverage the resources and time that were available. He was/is grateful for the support provided in this endeavor by his chair, dean, and other administrators. To their great credit and sometimes sacrificially, they did provide significant support, both tangible and intangible, within the constraints upon them.
Probably the most pivotal method used to leverage existing resources was the heavy involvement of undergraduates in the research, essentially identically to how graduate students are used in larger programs. Most were electrical engineering majors, but a few were mechanical engineering, chemistry, and physics majors. The set has also included women, minorities, and international students from all over the world. The author was very selective regarding which students were invited to participate, with preference given to those with both good grade point averages and obvious practical skills and common sense. Hence, there have been only a couple of instances, over nearly a hundred undergraduate research assistants used since 1982/1983, that have not been basically positive, albeit not always perfect, experiences for both the student and the author. These students were given significant responsibility and flexibility in the research, without micromanagement per se. Weekly research meetings, periodic visits by the author to the laboratory, and an open door policy regarding questions and problems were successful in providing the students the broad guidance needed.

The field of research was semiconductor thin films and methods for depositing such, with emphasis upon liquid phase methods, for example, electrodeposition and chemical bath deposition that required minimal equipment and laboratory space. In more recent years, the work has expanded to involve other types of thin films, and development of environmentally benign processes and materials related to such. This field is highly multidisciplinary, cutting across electrical, chemical, and materials engineering, as well as chemistry and physics. It was/is also a strong area of interest in the scientific/engineering research community, for example, in regard to thin film light detector and solar cell materials, and has elicited respectable external support throughout the years, including that of the National Science Foundation, the National Institutes of Health, the Environmental Protection Agency, various state programs, and private industry. The greatest degree of support has been from NASA, including three NASA EPSCoR grants, a NASA JOVE Program grant, and several student grants. The author was also a NASA/ASEE Summer Faculty Fellow in the summer of 1987 in the Photovoltaics Branch of the NASA Lewis (now Glenn) Research Center, and also spent a portion of the summer of 1992 at NASA Marshall Space Flight Center as part of his JOVE project.

The research has generated many papers, presentations, and even a patent, with most of these having the undergraduate research assistants as worthy coauthors, and sometimes the primary author. In recent years, almost all of the undergraduate research assistants have made presentations, typically multiple ones, at regional conferences. Several have won awards for the best undergraduate presentation within given disciplinary categories. Several have also been recipients of specifically student grants, for example, from NASA and the Arkansas Scholars Undergraduate Research Fellowship (SURF) Program. Several have gone-on to successful graduate education experiences at larger institutions, with four having received Ph.D. degrees, and numerous ones having received master degrees in electrical engineering or closely related areas. Essentially all have gone-on to successful engineering careers, either with or without graduate degrees. In multiple instances, employers and/or graduate school representatives have expressed how impressive and important the undergraduate research experience was, not only in the initial hiring and financial support decisions, but also in the rate and quality with which the new hires performed their responsibilities. The success of these students has been a major
component of the author’s positive reputation in this research arena.

The author has made a strong effort to integrate undergraduate research in semiconductor and thin film materials with instruction. For example, he developed two lecture/laboratory course pairs in semiconductor materials and devices, and a lecture course in optical electronics, all at the undergraduate level. He sometimes augments the students’ research by having them enroll in special topics courses such as Special Problems in Electrical Engineering, Student Research in Electrical Engineering, or Honors Senior Thesis, with appropriate deliverables such as technical reports. He frequently draws from his research in providing examples and practical applications in other electrical engineering courses that he teaches.

Thus, although not without some occasional challenges, the participation of undergraduates in research has been clearly mutually beneficial to all involved at the time, and later. Much more detail regarding this earlier period in the author’s academic career can be found in the references. The next section will further detail some of the specific advantages of such for both students and faculty, particularly in small and/or undergraduate programs.

**Benefits of Undergraduate Research for Students:**

Participation of undergraduates in faculty research offers a variety of strong benefits. Participating students acquire a much better understanding, appreciation, and even intuitive sense of the underlying theory and mathematical models covered in associated lecture classes. For example, in the author’s research, students have frequently expressed that they didn’t really understand chemistry until they applied it in the actual synthesis of semiconductors and other materials. Students also acquire “practical”, hands-on research experience, for example, with experiment design, data reduction, and instrumentation, and a variety of skills ranging from the mundane, for example, machining of parts and soldering, to advanced, for example, computer data reduction and simulation. These also can lead to a better appreciation, passion, and ambition for the engineering/scientific profession and associated graduate education and/or career. The students tend to acquire a better understanding of how technology fits into and sometimes conflicts with the societal infrastructure, for example, with environmental, health/safety, and economic issues.

Students also acquire skills in problem solving. The research is truly “original”, and frequently presents new challenges that must be overcome through creativity, resourcefulness, and perseverance (; “that’s why they call it ‘research’ ”). Students gain enhanced experience with teamwork, leadership, and the give-and-take of all human relations. They also gain their first experience with working under the direction of a boss that is a technical professional, although most do have previous employment experience.

A powerful benefit is the practice and skill acquired in technical communications: written, oral, and increasingly electronic. Undergraduate research assistants make biweekly presentations, currently usually with Microsoft PowerPoint and computer-interfaced projector, at the weekly research group meetings. These are critiqued by the author and the other students on evaluation forms that are collected by the author and returned to the presenter as feedback. Most students
also prepare and submit abstracts for, and make presentations at, regional conferences, providing additional experience with “real world” technical communication, as well as how to field questions and network with other professionals.

More tangibly, the research experience is usually also a “job”, with well-defined hours and pay. Thus, the students pick-up additional income in a job much more interesting and beneficial to their future career than typical, low-technology, off-campus employment. For some, this just provides extra spending money, but for others, is essential for paying tuition/fees and other bills. In some cases, students may also or alternately receive course credit for their research, for example, through the courses Special Problems in Electrical Engineering, Student Research in Electrical Engineering, or Honors Senior Thesis.

Most significant are the enhanced confidence, vision, credentials, and marketability that the experience provides. There is little doubt that the experiences have had a pivotal impact upon the future of many participants. For example, multiple students that did go-on to graduate school at other institutions have expressed after-the-fact that it is very unlikely that they would have done so without the undergraduate research experience and the encouragement and mentoring by the author to do so. Many stay in-touch with the author, and, again, repeatedly express their appreciation and respect for both him and the experience.

**Benefits for Faculty:**

Utilization of undergraduates in research is not only beneficial to students, but also to faculty mentors. It provides extra hands and person-hours to perform all of the needed work. This is particularly true in purely undergraduate programs in which the faculty workload may be high, and in which there are no graduate students. In these cases, undergraduates may provide a critical, versus only valuable, role in enabling research to be accomplished.

The use of undergraduates in research, even still a little novel, also serves as a good venue for publicity and recruiting. The author has had several local newspaper/newsletter articles and both radio and television interviews covering his research, and involvement of undergraduates in such has usually been a key focus. His college has also used it as a competitive advantage and a recruiting tool for new students and retention of such. It also serves as an avenue for undergraduate participation in conferences, programs, and funding opportunities targeted specifically at undergraduates, hence, broadening the scope, audience, and impact of the research for the faculty member. For example, the National Science Foundation has the “Research in Undergraduate Institutions” (RUI) and “Research Experiences for Undergraduates” (REU) programs. NASA similarly sponsors a variety of programs advocating undergraduate research, both at the student’s home institution and as interns at NASA sites. Most funding agencies strongly encourage the involvement of undergraduates in research and look favorably upon it in proposal reviews as long as the complementary research infrastructure and “good science” is adequate to support the tasks proposed. As discussed above, it also serves as an opportunity to synergistically integrate instruction and research through special topics-type courses focusing upon research, and standard classes in the faculty member’s research field, as are common at the graduate level but less so at the purely undergraduate level.
For the university, undergraduate research is an extra “service” and “value added” provided to some students. This increases satisfaction in and loyalty to the university, and serves as powerful word-of-mouth advertising and image enhancement, in turn, improving recruitment, retention, and external (legislative, alumni, funding agency, etc.) support. From a societal perspective, undergraduate research, over the long run, produces a larger and better-trained pool of professionals, notably scientists and engineers. It enhances thinking and problem solving skills in practitioners-to-be, hence, increasing competence. It fuels a greater interest in the profession, hence, enhancing overall productivity of the society and nation.

Recent Changes in the Undergraduate Research Paradigm:

Over the last 30 years, the author has observed evolving trends in undergraduate research. Some are related to programmatic issues, some to changes in technology, and some to changes in student backgrounds and perspectives.

One major and primarily deleterious factor is the large increase in the number of students who have significant off-campus jobs. This has limited the pool of students available as undergraduate research assistants. In a few instances, students invited to join the author’s research group have agreed to quit their current job to do so. However, since they normally don’t work as many hours (typically 12-17 per week) or receive as much pay (usually minimum wage) with the research position as with the external job (sometimes 20-40 hours per week at somewhat above minimum wage), some have simply declined the invitation due to financial constraints. In a few instances, the author has allowed, with hesitancy, research assistants to join his research group and keep an external job “after hours”, but this has invariably caused major problems with scheduling research hours, unexpected emergencies at the other job site, and particularly student focus, passion, energy, and even sleep/rest. It simply does not work well, regardless of assurances by the student up-front that it will. In general, this is more of a problem with domestic students than international students, since job opportunities for the latter tend to be somewhat limited and they are generally very eager for an opportunity to make some money and gain the additional experience and credentials. Probably not a national trend, enrollment in international students decreased significantly at the author’s institution from the mid 1990s to the early 2000s, further decreasing the pool of potential undergraduate research assistants, but has started to increase significantly again in recent years.

As discussed above in the paper, undergraduate research is now much more “in-vogue” and supported than it was when the author started his research program in the early 1980s. This has led to a much broader set of funding, conference, and programmatic opportunities targeted specifically at undergraduate research. In addition to the specific undergraduate research-oriented initiatives of federal funding agencies such as NSF and NASA, and encouragement of undergraduate participation in national/international conferences sponsored by engineering and scientific professional organizations, for example, the Institute of Electrical and Electronics Engineers, there are a variety of these at the regional, state, and local level. For example, Arkansas sponsors the Scholars Undergraduate Research Fellowship (SURF) Program that annually awards research fellowships/stipends to a large number of undergraduates and faculty
mentors within the state. Several of the author’s students have received these. In conjunction with NASA, the Arkansas Space Grant Consortium also supports undergraduate participation in its funding programs, for example, NASA/ASGC Workforce Development Grants for students. These involve initial research at the student’s institution, culminating in an internship at a NASA site. There also several state and regional conferences either targeted specifically at undergraduate research, for example the annual Arkansas Undergraduate Research Conference, or encouraging undergraduate presentations in regular sessions, for example, the Arkansas Academy of Science meetings. Some award prizes for best presentations in various scientific and technical categories, and the author’s students have placed in these many times. The author’s university annually sponsors an Undergraduate Scholars Day which also provides opportunities for undergraduates to make presentations over research and scholarship, makes travel funds available through its Office of Research and Technology Transfer for undergraduates to attend and make presentations at conferences, and strongly supports inclusion of undergraduates in proposals requesting seed funding through the internal Faculty Research Awards Fund and Committee.

True research (versus only “scholarship” in the broader sense) is now better supported through a variety of instructional and programmatic venues. In addition to Special Problems in Electrical Engineering and Student Research in Electrical Engineering courses taught through the author’s program, the College of Engineering has an Engineering Internship course that facilitates course credit for real world, off-campus experience with employers. Although rarely an avenue for pure/basic research, it does support applied research and development activities of undergraduates under the supervision of engineering personnel at regional industries.

Research can also be tied to the Honors Program at the author’s institution through Honors Senior Thesis courses in which students, directed by an advisor and a committee which also includes the Director of the Honors Program, define and conduct a high-level research, scholarly, or creative/artistic project, and complete and defend a comprehensive thesis over the work, almost identical to as at the master degree-level. This experience provides graduate school-bound undergraduates a powerful head start toward their graduate education, and solidifies skills associated with the complete research experience.

The increased popularity and acceptance of undergraduate research at the national/international level has led to the author’s university being more aggressive in publicizing such. When the author started-out, there was almost an embarrassment among some that solely undergraduates were involved in the research, since it highlighted the fact that the program was purely undergraduate and the university was just a master-level institution. However, as the author and other university faculty were very successful in conducting top-notch competitive research with such, and as undergraduate research began to be promoted at the national level, this changed so that the university’s undergraduate research emphasis became a strong competitive advantage, selling point, and recruiting tool.

Another powerful factor impacting undergraduate research (as well as all research) has been the personal computer, Internet, e-mail, and other “electronic” technology. This has obviously greatly increased the rate at which data and information can be obtained, processed, stored, and communicated. It has also minimized the importance of maintaining voluminous sets of paper
copies of items such as catalogs, reference/data books, data sheets, and forms since most of these can be obtained and/or stored electronically. Data can now be acquired, processed, stored, and graphed without the need for laboratory notebooks and graph paper. Internet search engines and company web sites now make it quick and easy to obtain vendor information on just about any product (although printed price lists are still sometimes hard-to-come-by). Key information that used to be only on paper, for example, standards, material safety data sheets, material and chemical properties, etc., can now usually be found quickly on-line. Searches of the literature, as well as the review process for journal article submissions, have also been expedited by on-line methods. E-mail has facilitated rapid, low-to-no cost communication all over the world, including the transmission of documents as attachments. Teleconferencing and videoconferencing have allowed full meetings to be conducted without expensive and time-consuming travel. Even cell phone cameras make it possible for research assistants to make impromptu photographs of research experiments and results. Wireless digital assistants have placed most of this technology in the shirt pocket, purse, and hand, making it available essentially everywhere at any time. Computer-based audiovisuals and interfaced projectors have replaced the old trusty overhead projector, and allowed the convenient inclusion of graphics, photographs, and even animation into presentations. Today’s students are definitely computer/electronic savvy, and typically have related skills in the cutting-edge technologies greater than those of some of the faculty. In principle (but not nearly as much in reality), all of these should greatly increase the quality and pace of research and its results.

However, this all has some subtle disadvantages, particularly with student research assistants. Modern students barely know what a real library is, and are usually hesitant to utilize one. Some have the attitude that if it can’t be found on the Internet within a minute or two, it’s not worth pursuing. This tends to minimize the comprehensiveness, accuracy, and precision of searches and information, and lead to too many “lick-and-a promise”/“band aid” solutions to problems: “If it’s on a web site, it must be correct; right?” The overall quality of writing ability has also suffered with the advent of e-mail. It is not uncommon, even among bright students, to see atrocious grammar, spelling, punctuation, and capitalization skills, not only with e-mail, but even with actual formal documents. It’s basically the same “good enough” mentality fostered by the technology (“I used the spell checker so what’s your problem?”). The author emphasizes to students, particularly research assistants, that the quality of one’s written communications is a major hallmark of others’ judgment of one’s professionalism, and should always be of top quality, even with e-mail, and particularly with presentations.

A related problem is simply the huge amount of time that undergraduate research assistants “waste”, during designated work hours, in constantly checking e-mail, browsing the Internet, and performing other computer and electronic functions not related to their research responsibilities. The author has seriously considered removing (but not yet actually done so) the computers from his research laboratories because of this. However, now the hand-held devices would probably make this even ineffective. He has strongly counseled with the students about this issue multiple times over the last few years, but with less than satisfactory results. This has been a major impediment to both the quantity and quality of the research, and interest in and focus upon such, conducted by the students over the last few years, precisely at the time in which this “revolution” in technology and communication should have greatly increased them.
There have been other evolving shifts in student backgrounds and perspectives. In addition to the off-campus jobs and electronic technology discussed above, today’s students and research assistants have a variety of other distractions, potential pleasures, and supposed responsibilities that detract from passion for and diligence with the research. Some of these have always existed, for example, boyfriends and girlfriends and sometimes family issues, but some have intensified. For example, the author finds that today’s students tend to be much more apt to consider a problem that a regular friend is having as a real crisis that requires his dropping his research and school responsibilities and going to the friend’s rescue, even when the friend’s family and neighbors are better poised to do so. Although loyalty to friends would be assumed to be a good thing, this typically is much overblown. Similar statements apply to the student’s own routine problems and responsibilities, for example, getting their car license renewed, going to the bank, or, very commonly, doing homework and studying for tests. They often feel that they are fully justified in taking time off from their research hours to do so, rather than arranging their lives to optimally handle and limit necessary responsibilities. That is, although capable of doing good work in short bursts, it’s difficult to get them to focus, persevere, innovate, and endure over the long run, further reducing both quantity and quality of the research. Many just do not consider the research position a “real” job since it is only part-time within the university, is indirectly related to their formal course education, and is not micromanaged. This allows some to rationalize and excuse their tardiness, absenteeism, minimal planning, procrastination (very common), and less-than-maximum effort.

Related to this is an overall decrease in true intellectualism and scholarly mindset. Very few modern students, including research assistants, have much deep interest, and, indeed, much time (from their perspective), to read the classics or the works of the pioneers in engineering and science, or pursue artistic endeavors. Few know how it feels to perform “back-of-the-envelope” calculations or derivations, or independently pursue some technical topic of interest. There are conspicuous exceptions, but these are uncommon. Most modern research assistants are a far cry from the author’s second research assistant who in the early 1980s would come back to the research laboratory in the middle of the night after a 2-3 hour nap after completing homework, and practice the cello while monitoring a thin film deposition experiment. He became a legend among the nightshift custodial staff. He is the same student who made the serendipitous discovery that led to a patent and went-on to obtain a master degree in electrical engineering from Purdue University and a successful career in the robotics field…

Conversely, most modern students are well-steeped in current superficial information from web sites and particularly various so-called scientific/technical programs on television. They are pretty good at discussing current events in engineering and science on a shallow, lay basis, and can ask some interesting questions and conceptualize interesting hybrid combinations of ideas. However, the real depth of understanding is often not based upon a sound understanding of underlying theory, as usually is acquired from one’s classes. They typically “don’t know what they don’t know”.

Modern research assistants also tend to not be nearly as well-versed initially with practical, hands-on skills as students 2-3 decades ago were, other than the electronic/computer-based “virtual”
ones. Few have ever built a tree house, repaired a flat tire on a bicycle, or helped their dads re-shingle the roof. Many have little experience with conventional hand and power tools. However, most actually do gain some of this experience as part of the author’s research group in the design and fabrication of “custom” experimental apparatuses.

Related to the job issues discussed above is the increasing tendency of some research assistants to express dissatisfaction with the relatively low hourly wages earned as research assistants. Most of the time this is at or near minimum wage, since minimum wage for undergraduates at one time was actually a university policy. That has changed in recent years, and the fact that some faculty members with external funding have begun to pay higher wages has motivated students to question the author on this a few times in recent years. This is understandable and not unjustified, but the uniform minimum wage in the past prevented precisely this type of case-by-case “negotiation” with research assistants about wages and raises. Now, it can become a bidding competition for students of top quality. Interestingly, students who obtain research scholarships or fellowships with lump-sum stipends essentially never question them, even when the actual equivalent hourly wage is still close to minimum wage. In this case, the honor and prestige may help compensate, although it is probably more because the one big lump-sum looks impressive and is not apportioned over time. For a variety of reasons, primarily increases in tuition and fees, and many students not wanting to live in the dormitories but instead in higher cost off-campus housing, today’s research assistants are more savvy about finances than typical ones used to be. Most are still interested in gaining experience and credentials, but many have to balance this with being able to pay all of the bills.

On the other hand, the author still occasionally has a student express interest in participating in research solely for the experience, usually after being told that there are no open paid positions. When this happens, the author will carefully interview the student and probe true underlying attitudes and capabilities. In a few cases, these students are brought on-board and, if working-out, will usually be moved into a paid position when one opens. Also, even the students hired into normal paid positions typically initially “observe”/“shadow” other research assistants for several weeks on their own time with no pay as a “probationary” “observation” period during which both the student and the author decide if the arrangement is going to be successful. If so, as is almost always the case, the students will go on the payroll in a few weeks.

**Current Challenges and Pitfalls:**

As implied in the above discussion, there are a variety of challenges and potential pitfalls associated with optimal management of today’s undergraduate research assistants. First is finding the proper balance between motivation (the “carrot”) and discipline (the “stick”). Modern progressive management theory favors the former, but the author has found that motivation is not sufficient in and of itself. A little correction, and sometimes a lot, may be required in some instances. Today’s young people are, by and large, used to getting what they want, how they want it, and are skilled at redefining situations to their liking and applying “civil disobedience”/“passive-aggressive” strategies to get their ways. This is usually not consistent with maximum research productivity. Absenteeism, coming late and leaving early, and lack of focus, initiative, and diligence have been major problems, with a few exceptions, among the
author’s undergraduate research assistants over the last 5-7 years. Yes, the students are sometimes overextended and strapped for time, but frequently these are due simply to poor planning, confused priorities, the inevitable distractions previously discussed, and sometimes a poor work ethic. The author frequently encourages, but sometimes has to chastise either individually or as a group depending upon personalities and circumstances. Termination or suspension are only rarely used since these students are, indeed, among the best and brightest, because significant time and training have already been invested in bringing them up-to-speed, and because some would simply move-on to another job because of lack of passion and commitment.

Related to this is the limited and continuously decreasing free time, due to increasing administrative and programmatic responsibilities, that the author has to directly manage, hour-by-hour in the laboratory, the students. Granted, increasing this direct involvement and oversight could significantly decrease the above problem, but keep in mind that the purpose for the undergraduate research assistants is precisely to leverage the author’s limited time, as is the standard model with minimally supervised graduate students, and these are already top-notch students, at least academically. There are weekly hour-long research meetings, the students are encouraged to take advantage of the author’s open door policy and discuss any research issues at any time, and the author does work in the laboratory as time allows. That is, it should not be a case of “when the cat’s away, the mice do play”.

Also related is the challenge of instilling true enthusiasm, focus, and, indeed, preferably near-obsession with/for the research. The author still distributes copies of relevant journal articles, discusses the broader societal benefits of the funded projects, hosts seminar speakers on a variety of engineering and science topics, encourages student membership in professional organizations such as IEEE, sends students to regional research conferences where most make presentations, includes students as worthy co-authors on papers, actively promotes graduate education and research careers, and a variety of other things that used to be highly successful in maintaining passion for the research and productivity in such. It’s just a fact that these are just not as successful as they used to be. Again, the author could be a constant cheerleader and hand holder, but there isn’t time, nor should it be necessary. Many students exhibit what one of the author’s colleagues (now retired) surprisingly said many years ago when a little frustrated: “I enjoy research, but there are a lot of things that I just enjoy more”, pointing to modern distractions, pleasures, and questionable (over) commitments.

The financial, time, and other challenges upon the students are, indeed, sometimes significant. There are far fewer students than there used to be that fit the model of a full-time student focusing solely upon college-related issues. Too many are barely surviving financially, logistically, and sometimes even academically. Notable exceptions are those star students on “full ride” or, at least, generous scholarships. These make usually desirable research assistants due to their academic ability and strong writing skills, freedom from heavy financial obligations, and usually strong ambition for graduate education and career. As discussed previously, it’s difficult to insist that research assistants not “moonlight” with other jobs, but in those instances in which the author has acquiesced on this, it has not worked and the students became undependable and basically worthless.
Another less serious challenge is the less-than-best preparation of modern students in mathematics, chemistry, and physics, at least in some cases. These are all important in the multidisciplinary semiconductor/thin film materials research. This is, of course, not unique to research. Some of the blame rests with the high schools, some with their college courses, and most with the students themselves, who just didn’t learn these like they really should have when taking the courses. Similarly, a relative lack of hands-on skills with tools, carpentry, machining, etc. is sometimes a minor challenge, but students typically come up-to-speed on these with on-the-job experience.

Facilitating optimal use of computer, electronic, and library resources is another challenge. As discussed above, this involves making sure that students, while on the job, use these technologies only for job-related purposes, not personal or course-related ones. This is much easier said than done, but should be the policy and goal. It is also useful to send research assistants directly to the library to learn about resources actually in the library, particularly research journals, and obtain actual paper copies of articles.

The reader may note that little has been said regarding the ability of students to actually perform the semiconductor and thin film related deposition and experimentation. That’s because that is rarely a problem in itself. When the personal and logistical issues are in-line, nearly all of the students can conduct excellent research. Most are intelligent, creative, resourceful, and rapid learners if/as they can be made to consistently focus and truly enjoy the research experience.

Opportunities:

There are a variety of potential opportunities related to undergraduate research. It should always be used as a strong selling point in research proposals, both for solely undergraduate and mixed undergraduate/graduate programs. That is, turn the lemon into lemonade and leverage the undergraduate research to one’s competitive advantage, both in the actual research proposed, and the related instructional, outreach, and job enhancement portions of the proposals. Pursue specific undergraduate-related funding opportunities such as NSF RUI and REU programs.

Another benefit that the author and his university have experienced has been opportunities to partner with the larger research institutions in the state in multi-institutional research proposals such as EPSCoR programs sponsored by NASA, NSF, DOD, and EPA. Several of these have been funded and have been a major boost to the author’s research program. Such programs usually encourage or require flagship institutions to, indeed, seek-out and partner with smaller, less research-intensive institutions in the name of research infrastructure development, economic development, and outreach. These opportunities have been real “win-win” opportunities.

The relationships so-developed led to several of the authors’ research assistants going to graduate school at the partner institutions, and an informal “pipeline” for such. Even better would be formal matriculation/transfer agreements between the institutions, and perhaps minor tailoring of the undergraduate programs at the undergraduate institution to better match the needs of the larger institution.
Another opportunity is applied research and development with industry. Such work is also generally a big “win-win” for all involved, certainly the students participating, who pick-up significant savvy about how the real engineering world operates. With relatively small high-technology companies, “Small Business Innovative Research” (SBIR) or closely related technology transfer (STTR) grant programs sponsored by various federal agencies (and comparable state programs) are ideal ways to kick-start and fund mutually interesting and beneficial research, and involve undergraduates in such an enhancement of the economic development/job creation aspect of the programs.

Also as implied earlier in the paper, undergraduate research presents additional opportunities for dissemination, say at conferences, sessions, and even a few journals targeted specifically towards undergraduates. This helps both the students’ and the faculty mentor’s reputation and funding credibility. There are also opportunities to integrate the student research with instruction through special topics-type courses, capstone design courses, senior thesis courses, and even regular courses with a strong overlap with the research. The research and instruction can mutually enhance the effectiveness of each other, and lead to publicity as “educational innovations”.

**Current Developments at the Author’s Institution:**

The research paradigm and infrastructure at the author’s institution is in a period of major transition that hopefully will further facilitate the involvement of both undergraduate and graduate students in faculty research. The university has recently made public announcements that research will, henceforth, be a major aspiration and mission, in contrast to its historical teaching mission. The administration is working with the legislature and the Arkansas Department of Higher Education to facilitate this transition as rapidly as possible. The campus Office of Research and Technology Transfer has been empowered to expedite a much broader research and funding agenda than in the past, and faculty have been advised that expectations for competitive, externally-funded research will be increased, especially for new faculty. Recent influxes of state and federal funds are expected to help in this regard, for example, in the establishment of new campus research centers, for example, in environmental sustainability and alternative energy, and in the acquisition of major research equipment.

Although overall positive, this does have potential to change the modus operandi of the faculty, and cause some “growing pains”, for example, as initial resources and facilities remain limited. Not everyone is enthusiastic about the changes, but the more research-active faculty hope that the initial challenges will be more than balanced by a better research infrastructure and associated rewards and gratification over time.

The College of Engineering is now making its first real entrance into graduate education, with a new engineering management master degree program in its second year. It is also preparing to request implementation of a research-based master of science in engineering degree program in the near future. The availability of graduate students hopefully will not replace, but instead complement and strengthen, the involvement of undergraduates in the research. Currently, the author has three undergraduates and one graduate student working as research assistants. The undergraduates are electrical engineering majors and the graduate student is a Ph.D. student in the
multidisciplinary Environmental Science Program with which the author is also a Faculty Associate. Current grants (at the time of this writing) include a new three-year NASA EPSCoR grant in partnership with another institution in the state, and a National Institutes of Health-funded Small Business Innovative Research grant in partnership with a high-technology company in the state. The former deals with development of high-efficiency solar cells through use of nano-structured compound semiconductor films. The latter deals with the spray deposition of semiconductor/polymer composite films for light detection purposes. The undergraduates play a major role in actual day-to-day deposition and experimentation in both of these projects.

Other Tricks of the Trade:

Many “pointers” regarding optimal management of undergraduate research assistants have been implied within the above discussions. Others that the author has found somewhat useful (but not fool-proof) follow.

1. Don’t be too casual, even with students that you know well. Don’t become one of the boys. Maintain a line of authority, always act as a true professional, and lead as much by example as by directive. Modern young people are very quick to detect inconsistency, hypocrisy, and compromised standards. They will use these to rationalize their own decreased performance, so try to not exemplify, “Do as I say, not as I do”.

2. Put policies and rules in writing and insist that students sign-off on them. The author has an “employment policy” and a detailed set of safety rules that student research assistants must read and sign every semester. He also has a detailed class policy document distributed to students in his regular classes. It’s also a good idea to prepare a “goals and responsibilities” statement for each student every semester. If it’s in writing, they can’t say that they weren’t aware. This protects both mentor and student, and minimizes misunderstandings and problems regarding expectations.

3. Once in-place, the policies and rules must be enforced with the “Red Hot Stove Rule”: If you touch the stove you get burned; if you break the rules, you get disciplined. Although easier said than done, concrete disciplinary measures (docking some pay, suspension, termination, etc.) may be needed with more severe or repetitive infractions. You can exhibit reasonable flexibility and compassion on a case-by-case basis, but you had better get your bluff in early. Nip developing problems in the bud before they become the norm. On the other hand, avoid serious humiliation of the students except in the most severe cases, and correct in private unless an admonition applies to the entire group.

4. Related to this, use the psychology to your advantage. Always make it sound as though you are doing the students the favor in employing them, not vice versa. Never let a student, even a superstar, either become or even think that he/her is indispensable, or paint you into a corner or get you over a barrel, so-to-speak. Once you do, you will lose control.

5. Certainly use the carrot as well as the stick. Give generous public credit where credit is
due. Praise and reward (say with perks and attention; doing so with money is more problematic) excellent research accomplishment and seniority, as well as personal characteristics such as punctuality, diligence, creativity, initiative, and reliability. Let it be known that the quality, length, and tone of recommendation letters and references will vary significantly as functions of the above.

6. Don’t let the undergraduate research assistants put the monkey back on your back when you have delegated something to them. Some will stall at the first challenge and run back to you wanting you to do the task for them. For routine such cases, insist that they exercise resourcefulness and perseverance and try, try again, unless it becomes clear that they just can’t overcome the challenge. Remember that they are there to save you time and increase your productivity, not consume your time with things that they can handle.

7. Any academic credit for research should be accompanied by a written and mutually signed set of “deliverables” and standards in an up-front mini-proposal, so that there will be no misunderstandings about what’s expected and how grades will be calculated. Also, spell-out exactly how many hours per week are associated with the course credit and how many are to be paid. Although not necessarily ethically prohibited, it generally is not a good idea to doubly reward a student with both pay and course credit for the exact same work. Also, keep full written documentation of the for-credit research work, say for ABET accreditation purposes, for example, the mini-proposal, status and mid-term reports, the final report, and laboratory notebook/log.

8. Don’t assume that students know more than they do. The author tends to be guilty of this since he uses top-notch students in a graduate student-like manner. However, he frequently is reminded otherwise. Within time constraints, train, instruct, and oversee, particularly when they are first brought on-board. Instigate a “chain-of-command”, formal or informal, based upon level, seniority, and performance, and utilize the other more experienced student research assistants, both undergraduate and graduate, to also mentor the new ones. The author depends heavily upon this mode of training. Also, utilize technicians to train and assist when appropriate with specific issues, for example, with instrumentation or machine shop work. Weekly meetings of the research group are excellent for addressing relevant non-emergency issues.

9. Even with limited budgets, do your best to provide the research assistants the supplies, chemicals, equipment, and facilities needed to do the work optimally. When needed and possible, pool and partner with other faculty, academic units, and even institutions. Although resourcefulness, creativity, innovation, frugality, custom synthesis and fabrication, and doing the best that you can with what you have are part of the territory of research, it is highly frustrating and time consuming/delaying to students to always have to “make do”. Aggressively lobby the institutional powers-that-be for tangible support, and keep a stream of proposals going for external support.

10. Although modern students with the electronic/computer mindset tend to resist, insist that students keep an actual paper laboratory notebook certainly at least once a day as a real
time, in-situ diary-like record of what they actually do and observe. This is important not only for patent and other intellectual property issues, but also to promote good planning and analysis of the work, as well as serving as a detailed archive of the work for years ahead. The author periodically refers to laboratory notebooks of research assistants from many years ago to check details or repeat experiments.

11. It goes without saying that students must follow all safety and security rules. Young people tend to think that “it can’t/won’t happen to me” and take shortcuts. Continuously promote, oversee, and document safety in all aspects of the work: electrical, chemical, mechanical, travel, etc. Work closely with the campus safety office in this regard.

The mentoring and development of undergraduate research assistants has been one of the joys of the author’s academic career. Although the times and students evolve, it is expected that undergraduate participation in research will continue to become increasingly widespread and important, say, with the recent emphasis on experiential and service learning. Faculty mentors must periodically reassess the methods used to optimally manage and inspire these students and make adjustments as necessary, even when challenging to do so. They should remember, in the final analysis, a major component of their professional purpose/mission is to help develop the total student, not only with knowledge, but also with character, thinking and problem solving skills, work ethic, and successful and happy life and career in the broader sense. The multi-faceted undergraduate research experience offers potential to foster all of these.

Bibliography:
