

# A Design of an Undergraduate Research Program in Chemistry

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**Abstract** Over the past two decades, renewed emphasis has been placed on the role that research plays in education of chemistry undergraduate students. Research faculty at undergraduate institutions face some unique challenges. Most PhDs are granted by large research universities, while most of academic jobs are at the smaller, predominantly teaching, institutions. We describe an undergraduate research program in chemistry that is expected to result in peer-reviewed publications. We offer practical advice of how an undergraduate student can be quickly and effectively integrated into the laboratory and research and explore potential problems and pitfalls based on fifteen years of experience and work with more than forty undergraduate students.

**Keywords** Upper-Division Undergraduate, Curriculum, Laboratory Instruction, Undergraduate Research

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## 1. Introduction

Undergraduate research is an important aspect of university experience for science students. Participation in research not only prepares undergraduates for further studies, but also introduces them to a new way of approaching and solving problems. There has been renewed emphasis on undergraduate research that began in the early 1990s[1,2] with the result that undergraduate research is now practiced in some form at most institutions[3,4]. Beer published guidelines for the supervision of undergraduate research along with a sample Undergraduate Research Student/Supervisor Contract[5]. Personal accounts of careers spent pursuing research with undergraduates that offered advice to new researchers, and provided descriptions of the best practices were published by several authors[6-12]. Other authors have proposed models for undergraduate research at predominantly undergraduate[13-15] and research institutions[16-18]. We would like to discuss our experiences, summarize the best practices, offer advice to new faculty, and propose some measures that may help institutionalize undergraduate research.

Most of the authors quoted above have noted the value and importance of undergraduate research with emphasis placed on the acquisition of knowledge and experience that can never be gained in an ordinary laboratory course. Some benefits of undergraduate research include:

i. students learn about perseverance, attention to detail, application of principles to practice and have a close working relationship with mentor that continues after the undergraduate studies are completed[19].

ii. It is a good way to teach technique, develop interest[20], and give students a chance to tackle real-world problems[14].

iii. It improves student learning[21], retention[22] and helps students select future career paths[3,23].

iv. It gives students an appreciation and knowledge of what scientists mean by "research," gives students an opportunity to accomplish something valuable from the scientific point of view, and makes an institution known because it contributes to a particular field of chemistry[24].

v. Students gain an appreciation for the quality of experimental data, the design of experiments, and the nature of science[19,25-28].

vi. Students experience an increase in creativity, critical thinking, excitement for science and an overall improvement in self-confidence and self-esteem[3,5,19].

vii. Sometimes students who are average in class work will show unusual talent when given an independent project[29].

viii. Research is a chance to improve our own skills as scientists, develop new ideas, rekindle our excitement in scientific discovery, transfer this excitement to others, and teach the techniques of scientific inquiry to our students[2,28].

ix. Students and faculty do it because it is fun. In its absence faculty lose their professional viability, facilities become outdated and the best students go to the other fields or other institutions[30].

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Only by carrying out research can student come to appreciate the value of a failed experiment and learn from it[19,31]. The failed experiment may have served as a control and it may be desirable that it failed[32]. However, typically that was not a desired outcome. In such cases, failed experiments force us to reevaluate our approach to the problem, consider alternatives, and redesign subsequent experiments. Furthermore, students also learn to treat and evaluate the data in a different manner. In an ordinary laboratory experiment, there is usually a single correct outcome and, frequently, a good and prepared student knows what it is supposed to be.

## 2. Specific Characteristics of Undergraduate Research

Compared to research carried out at typical research institutions (large research universities, government laboratories, industrial research laboratories, various research institutes), undergraduate research is associated with unique challenges. By being aware of them a capable researcher may be able to design a competitive and vibrant undergraduate research program.

### 2.1. Challenges Faced by Faculty at the Predominantly Undergraduate Institutions

Most science PhDs are granted by large research universities, while most of academic jobs are at the smaller, predominantly undergraduate, institutions. It is interesting that very few graduate students in the natural sciences are familiar with the job situation in academia. All too often new faculty expect to have similar levels of funding, facilities, support and expectations that their PhD supervisors had. Thus, they may experience difficulty in adapting to a primarily undergraduate environment. Even recent Ph.D.s with postdoctoral training may lack experience in developing undergraduate research projects and in handling undergraduate researchers. Their experiences have been in research laboratories filled with graduate students, postdoctoral fellows and with high quality research equipment.

Furthermore, a faculty member at an undergraduate institution may face isolation. At most undergraduate institutions, a faculty member will often be the only expert in the area. This stands in stark contrast to a research university, which usually has several faculty members in a given area along with associated postdoctoral fellows, graduate students and technicians. Thus, one may be surrounded by dozens of experts.

Yet another challenge is time management[33]. At an undergraduate institution, a faculty member must balance higher teaching and service requirements while starting and carrying out a research program. They may remember instances where their Ph.D. supervisor left for a conference and casually asked a postdoctoral fellow or a graduate student to take care of his class. This is unlikely to happen at a predominantly teaching institution. There are no graduate

students and postdoctoral fellows to be asked and, furthermore, institutional policies and practices are unlikely to tolerate such a practice.

Finally, an undergraduate institution will likely have limited funding and facilities for research[6,33-37]. The only question is just how limited they are, as there is certain level below which it is not possible to carry out any meaningful work.

### 2.2. Differences between Graduate and Undergraduate Student Researchers

It is tempting, particularly to a new professor, to treat undergraduate students as “little graduate students.” In 1932, Smith wrote “...there is no essential difference between the research of graduate and undergraduate students...”[24]. It is safe to assume that today most professors at undergraduate institutions would disagree. Undergraduate researchers are fundamentally different and require a different approach[32]. Besides the obvious difference that undergraduate students have considerably less time to spend on research, other differences include:

- i. level of knowledge, which varies considerably. Some students may already operate at a graduate level while others may lack fundamental skills.
- ii. technical skills, which are related to level of knowledge, but also dexterity, confidence and interest.
- iii. commitment as undergraduates are “trying” or checking out whether work in a particular area is for them, graduate students are already committed.
- iv. maturity, which varies considerably with undergraduate students often taking their responsibilities less seriously.

Training and preparation of undergraduate students should be designed to address these differences. Finally, a professor must be understanding of students’ need to do well on placement exams and secure admission to a graduate school. Students should be given time off for study.

## 3. Preparation for Research

Success in undergraduate research is seldom a result of an accident or luck. Sustained successful undergraduate research program is a result of careful and extensive preparation.

### 3.1. Recruitment and Selection of Undergraduate Research Students

One can use classes and teaching laboratories to attract research students. While the presentation of research topics in the classroom takes away from the time needed to present the course material, it was successfully introduced at the University of South Dakota[38]. Teaching laboratories may be more suitable for student recruitment because they provide more time to discuss research topics. In addition, a professor may want to set up his own research experiments in a fumehood, if it is not needed for a particular laboratory session, to run concurrently with the lab. They are likely to

spark students' curiosity and provide good starting points for discussion about research. At our institution, students can take an elective one-credit course in which professors present their research.

When it comes to the selection of students, there is an important difference as to whether undergraduate research is optional or required. If a professor has a choice, avoiding potential problem students may be more important than recruiting one or two exceptional students. If research is a required component of curriculum, a professor may have little choice in selecting students and may have to take all or most of those who are interested.

### 3.2. Preparation of Students for Research

Research students must possess sufficient knowledge and skills. Therefore, students need to complete appropriate course and laboratory work prior to engaging in research. Introductory lecture courses and laboratories should be designed to prepare students for research. There are numerous examples in the literature about designing teaching laboratories so that they either mimic research or include actual research[13,35,39-47].

It is important that a student is emotionally prepared for research[2]. Occasionally, a good student who in the professor's estimation is ready and capable of carrying out research is intimidated by the prospect of independent work.

### 3.3. Training of Undergraduate Researchers

Training of undergraduate students overlaps with their research as is the case with most research carried out in academic labs. Most, if not all of the training will have to be done by the professor. Unlike graduate students, it cannot be expected that all research-seasoned undergraduate students will effectively train new undergraduate students. An assumption that they will and that one can design undergraduate research program around it is frequently encountered in grant applications of new professors from undergraduate institutions.

Spector provided a set of guidelines for training and managing undergraduate research students as well as insight into numerous other issues of interest to supervisors of undergraduate researchers[32]. Since the early days of undergraduate research, a common theme has been that a student should not be used merely as a "pair of hands" [20,24,48,49]. They must understand the project and be creative participants. Unfortunately, some students are quite happy to be "pairs of hands" and perform technical aspects of research projects without understanding their purpose.

While we would have preferred otherwise, we have to agree with Johnstone and Pickering in their assessment that students cannot learn techniques and theory at the same time[50,51]. One approach we found to work well when teaching technique is to train students "backwards." That is, they first learn the technique they will use the last in the actual course of research. When trained in the conventional "straightforward" way, students often make mistakes that result in the waste of time and materials, and may discourage

them from future work. In knowing what the next procedure is, and what it takes for it to be successful, the student will understand the purpose of the current operations and their goal. In the case of organic synthesis, training starts with the characterization and identification of an organic compound, which are the final steps in synthesis of a new compound. That way, student understands the need for a pure product, and not merely a good yield. Next, the student is trained in the isolation of the reaction products. After knowing how to isolate a product, a student is less likely to make mistakes such as using too much of reaction solvent, or the wrong one, which would make the isolation (e.g. by extraction) of the product difficult. Finally, students are trained in setting up and carrying out reactions.

While they are learning experimental techniques, it is a good idea to have students draw a great deal. It is best if the drawing is done by hand. ChemDraw[52] and ChemSketch [53] are also acceptable. However, one should not allow students to take photographs. The purpose of drawing is for students to observe and record their observations. Only by drawing will they notice minute details that they otherwise would have missed.

Once the basic training in experimental techniques is completed, the emphasis shifts from drawing to writing. Research students should write a great deal. It may be a good idea to advise them to have two notebooks – one official laboratory notebook and another student notebook for themselves. The student notebook should be for everything – notes of meetings, writing down important ideas, questions, results of literature searches and so on. However, it should not be a notebook where students enter raw experimental data only to copy "cleaned" data into the official laboratory notebook.

At our institution, a written collection of Standard Operating Procedures (SOPs) is maintained as a safety requirement. As SOPs provide detailed written instructions on carrying out experimental procedures, they also aid in the training of new researchers and ensure continuity. A student who has developed, or learned a new technique provides a written set of instructions that becomes a part of the SOPs collection, and is thus available to the future students.

Another good practice is to have students provide regular, for example monthly, written reports. The benefits of written progress reports are numerous. Students learn to record their observations and results, thus making it easier to discuss projects in a meeting, write a thesis or a manuscript, or prepare a poster. The written record is a way of providing students with immediate feedback. Sometimes a student does not realize that his work is not satisfactory until his monthly report is due and he finds that he has very little to report.

Regular meetings are an essential component of training. They provide an opportunity for students to discuss any issues of importance, and for the professor to provide feedback. We hold two types of meetings. Group meetings, in which all available students participate, and individual meetings, in which a professor discusses the monthly report with the student and provides feedback.

Finally, a conference presentation or a journal publication frequently serves as the conclusion of a student's work and training. It is also a final opportunity to correct any misconceptions the student may have. Furthermore, for many students, the possibility of a presentation or a publication provides increased motivation to complete the work.

### 3.4. Selection of a Research Project

#### 3.4.1. General Considerations

When selecting a project, one should consider factors such as: Who else is working in this area? Is it an area of vigorous research with many high calibre researchers in it? If so, an undergraduate researcher may not be able to compete. Undergraduate research is carried out with considerably lower level facilities. Furthermore, the tempo of the work is much slower. It may take an undergraduate research group more than six months to accomplish the amount of work that may take a postdoctoral fellow only two weeks in a research-intensive laboratory. At the other end of the spectrum is work in an area that is obsolete. The study of an old problem that has already been thoroughly investigated will probably provide little new information and publication of the results will prove to be difficult.

There is a need to initially carry out an extensive literature search, and then keep up with the literature on a continuous basis. This may be a challenge at an undergraduate institution, with a professor having only a limited amount of time and the institution may have limited library facilities, such as electronic subscription to only a few journals.

#### 3.4.2. Preliminary Work

Most likely, a professor will have to carry out the preliminary work as well as finish the project. With very few exceptions, undergraduate students are not capable of carrying out preliminary studies. For example, if an initial experiment fails, it may not be clear whether the student carried it out correctly and whether his or her technical skills were adequate.

#### 3.4.3. Level of Difficulty

Numerous authors have already emphasized the importance of the selection of a suitable undergraduate research project [6,8,20,24-26,29,34,49,54-57]. Obviously, a project should be at an adequate level. Ideally, neither too trivial – it cannot be a high school project, nor too advanced – undergraduates must be able to handle and understand it. It should present a challenge, and require student to do additional reading and learn new things.

#### 3.4.4. Facilities

A professor should be able to carry out the project with the existing facilities. This may be an obvious point, but a novice researcher sometimes plans for and secures the necessary materials, supplies and facilities only for a straightforward

successful project. When problems appear, such researcher may not be able to continue, as he or she lacks facilities to address them. Therefore, the facilities should be adequate for alternative approaches to the problem at hand, and should be sufficient to address anticipated problems and contingencies. Otherwise, frustration may set in. This is also an instance in which collaboration becomes helpful. It provides access to new facilities and to fresh ideas (*vide infra*).

At a large research university, a research laboratory is usually very well equipped, as often there is stored equipment left from earlier projects. Equipment can also be borrowed from other research groups on campus and research funds may be available if a purchase is necessary. This is where the transition to a small teaching intensive institution may prove to be difficult for someone who is accustomed to or solely familiar with such conditions. One may not even realize that there is a potential problem until it appears.

#### 3.4.5. Project must be Interesting

Finally, the project should be interesting to the students. They are unlikely to voluntarily participate in work that they view as tedious and boring. One way to avoid this is for a professor to have several very different projects available, and allow students to choose. After some time, the professor will be able to judge which types of projects students find attractive.

## 4. Managing Undergraduate Research

### 4.1. Research Schedule

As mentioned earlier, professor will have to start and finish the project. Therefore, not all available space should be assigned to research students. Furthermore, a professor must have some research time separate from the time spent with students.

One of the issues related to the organization and management of undergraduate research is whether to focus on research in the course of an academic year or to carry it out over the summer, or both. It is difficult to provide a general advice as a great deal depends on the particular institution. At some institutions, in the course of the academic year, all of the laboratory space is occupied by teaching laboratories and the summer is the only time when research is possible. At other institutions, particularly some residential colleges, students leave for home over the summer and are not available for research. In addition, a professor should consider his or her situation and objectives. Is it better to spend the summer working alone on a project, or working with students? Supervising several marginal students (*vide infra*) could result in a wasted summer, which may have serious repercussions for a professor on a tenure track.

### 4.2. Team Work

Frequently, undergraduate research students do not spend enough time in the laboratory to successfully complete a research project. It is a matter of preference whether to break up the project into small research projects and assign each to a single student[26], or to assemble a team of students to handle the entire project[28,58]. The former arrangement ensures that each student receives complete training. When working as a team, undergraduate students sometimes “specialize.” Thus, an organic synthesis team ends up with a student who sets up reactions, a student who runs chromatographies, a student who takes NMRs and so on. However, it should be noted that some supervisors have made a good use of such “specialization”[28]. While students should collaborate and help each other, they also should be trained in all aspects of chemical synthesis (preparation, isolation, purification and identification). This is the best accomplished when a student is responsible for his or her own project. Some of the problems we encountered with a group approach include the “observer/free loader problem” (*vide infra*)[41,59], group politics and the fact that the group is only as fast as its slowest member. The last one is a particularly difficult issue when students have different and legitimate objectives. For example, one student may be very interested in getting a publication, and is prepared to put in long hours while at the same time another student is trying to get into a Medical School and is preparing for the MCAT and shadowing doctors, while putting only the required minimal time into the research project.

There are several benefits of team work for undergraduate students. They learn to work with others, learn to be a part of a team, and, if the team works well, they may be able to accomplish more than a group of individual students each handling a part of the project. However, there are also numerous problems. As already mentioned, a team is only as fast as the slowest student, some students end up being “observers,” or “free loaders” (described below), and sometimes there is group politics.

Team work, but also work by a group of students on individual projects in a single research group, is subject to various forms of group politics. To minimize it, students should communicate directly to the professor and not through each other. One example of group politics that we occasionally encountered is a chasm between juniors and seniors. While they may not be openly hostile to each other, there is often an obvious lack of enthusiasm for working together, which helps explain why they will not train each other. Finally, some students prefer to have their own project so that they can claim ownership of and can take credit for its success.

### 4.3. Collaboration

For a professor who wishes to pursue research with undergraduates, collaboration is not only advisable but may be essential to success. Through collaboration, one may be able to address numerous problems that plague researchers at undergraduate institutions.

A researcher at an undergraduate institution should strive to establish both horizontal and vertical collaboration. Horizontal collaboration is collaboration with other researchers at the same level – the other scholars who carry out research with undergraduates. It usually extends across disciplines and opens possibilities for interdisciplinary and multidisciplinary work. Even if it is within the same discipline, it is helpful as it may open access to additional facilities and instrumentation, as well as shared supervisory responsibilities. Vertical collaboration involves work at different levels. A researcher at an undergraduate institution is ideally positioned to collaborate both with higher level and lower level institutions.

Other authors have already stressed the benefits of vertical collaboration[36,60,61]. The benefits of collaboration with research intensive universities are substantial – possible access to instrumentation and facilities, access to graduate student expertise and experience, opportunities for undergraduate students to be exposed to a graduate laboratory, and the possibility for the placement of undergraduate students who can get an early start on graduate studies.

At the other end of vertical collaboration is work with two year colleges and high schools. Some examples of collaboration between two year colleges and universities have been reported[9,10,36,37,60,61]. Two year colleges offer access to additional students, and provide the potential opportunity to recruit transfer students. Collaboration with faculty at two year colleges offers the possibility of shared supervisory responsibilities, which alleviates time constraints. Collaboration with high schools may be equally beneficial. Interested high school students can be paired up with undergraduate research students and under the guidance of professor, assist in the completion of ongoing projects. Some high school students may be surprisingly capable of doing very good laboratory work and learning things quickly. A professor has an opportunity to work with capable and motivated students who may remain in the laboratory for an appreciable length of time if they continue undergraduate work at the same university.

This is also a recruiting opportunity for the institution as the high school students have the opportunity to familiarize themselves with the university and the available facilities.

Finally, if high school students are paired up with qualified undergraduate students, this is an opportunity for undergraduate students to gain supervisory experience – the value of it cannot be underestimated. For most undergraduate students, this is the first time they are placed in a supervisory role. They gain an appreciation of issues and challenges that come with supervising others. In graduate school, such students are likely to have a better understanding of a professor’s responsibilities and are likely to be better team players.

### 4.4. Termination of a Project

When it comes to student research projects, a professor

must be prepared to make a difficult decision and end a project early before significant time and resources are expended (“fail early and fail cheap”). If the project is not working out, there is only a very narrow window of opportunity to change it. Pouring additional time and resources into it is unlikely to bring success and continual failure can be frustrating to an undergraduate research student[32]. A supervisor should have a back-up plan, be ready to change the direction of the project or the project and, finally, identify the reasons for failure. Some questions to ponder include: Was preliminary work sufficient? Are additional studies needed? Should the project be redesigned? Was the project a good match for the student’s abilities? Would the project be successful if given to another student with different interests, abilities, or time schedule?

#### 4.5. Problem Students

Like other aspects of undergraduate education, undergraduate research has its share of problem students. This is particularly the case when research is a required part of the curriculum. With some experience, a professor may be able to identify those who will be a problem for his research program and his research style. Here we will discuss only a few and by no means all of the possible types of problem students. For a particular area of work, a different type of student may present a problem. Thus, a student may be a problem in a group that is carrying out organic synthesis, but perform quite well in a group dedicated to instrumental work.

##### 4.5.1. Professor-dependent Students

An undergraduate student who wishes to participate in research must be capable of at least some independent work. Therefore, not every academically successful student is a good research student. A few students, sometimes academically rather successful, will not do anything unless they are given detailed instructions and told what, when and how to do it. Those are students who are either intellectually lazy or insecure. Occasionally, such a student excels in course work, but does not appear to be capable of any meaningful independent laboratory work.

##### 4.5.2. Marginal Students

Marginal students lack the ability, the interest or both to some degree. In 1941, Yoe wrote “The professor can train the right type of potential research student but he can’t put brains in his head”[49]. While such an attitude would not be acceptable today, marginal students present a problem for a research group. Depending on the program and the institution, a professor may have to accept some such students. While some who are able to adapt are occasional and pleasant exceptions, with most of them it is the best to limit the damage. A marginal student is one who, as a part of a team, is the most likely to be an “observer” or a “free-loader.”

The “observer” and the “free-loader” have in common that,

as a part of a team, they do little or no work. They differ in motivation. An “observer” may lack the initiative or confidence to assert oneself as a part of the team. When assigned a project of his or her own, an “observer” may do quite well. A “free-loader” may have the ability and the confidence, but is quite happy to let others do the work. When assigned a project of his or hers own, such a student will still do little or no work and offer plenty of excuses.

A student “who has perfected the art of getting by”[62] can be very frustrating. They are capable of quality work, but they do just enough to get by and get the grade they desire. As many of them desire an “A” this is a serious problem. As soon as they notice that the professor is satisfied, they scale down on their efforts and laboratory time. When they are told that they should put in more effort, they are so apologetic that a novice professor may feel guilty for reprimanding them. Then they come back to the laboratory and resume work only to scale it back down as soon as they notice that the professor’s attention is elsewhere. As such students are mostly concerned with an outcome, such as a grade, and not with doing a good job, the quality of the data they obtain is sometimes very poor. In general they perform below their promise and the professor’s expectations. It is with students like these that written policies and detailed grading schemes are very helpful[5, 32].

##### 4.5.3. Pre-med Student who “Lost Interest”

We will end our, by no means exhaustive, list of problem students with a “pre-med who lost interest.” Many medical and other professional schools consider activities, such as research, as an asset. It looks very good on a student’s CV and gives the student something to discuss at an interview. Participation in research may help a student stand out compared to other students with high GPAs and high MCAT scores. The typical student in this category is a highly capable A student. Early on, such a student puts in reasonable or even high degree of effort and does excellent work. However, as soon as such a student gets a letter of recommendation, he or she stops any work. One of the primary issues with this type of student is that there is no indication that they are about to stop work. The only way to get such a student to do the remaining work is to resort to punitive actions. The best way to handle this situation is to be prepared and flexible. Thus, if the student turns out to be good, highly motivated student who keeps up a high performance, a professor should be ready to put more time and resources into the project, and if the student starts slacking off, the professor should be prepared to scale it down.

##### 4.5.4. Possible Solutions

As all of the aforementioned problem students take away something from the rest of the students, it is important to carefully manage them, as well as any other problem students. Previously mentioned “fail early and fail cheap” advice also applies to handling marginal students.

Furthermore, if a student's work is not satisfactory, the student should be informed about it as soon as possible and, thus, be given an opportunity to improve. The discussion of the required monthly reports provides a suitable venue.

One way to address the issue of problem students is to have students start research as juniors. In general, there is little difference in the ability of junior and senior students. Advantages to the student of starting research as a junior are that more time can be spent in the laboratory as the student is not yet taking entrance exams, submitting graduate school applications and going to interviews. If the research is successful, the student will be able to present it at a conference or even have it published during their senior year. That way such accomplishments will be considered by the graduate school admissions committees. Advantages for the professor are that the student will likely spend more time in the laboratory, as distractions related to graduate school applications are still a year away. Furthermore, common "rewards" that end motivation of some students to carry out research work, such as letters of recommendation and conference presentations, are a year away, and the student will likely spend time in the laboratory and do a good job. Moreover, under these circumstances it is easier to spot problem students such as marginal and premed-who-lost-interest students. As students are not in the graduate school application process yet, they have fewer legitimate excuses to avoid research work. Finally, it is also easier to deal with problem students, as asking them to leave the research group has a lesser impact on their future. They have more than a year to complete their studies and can make up for the lost course credits. On the other hand, asking a senior to leave may delay his or hers graduation date and jeopardize admission to a graduate school.

#### 4.6. Good Students

Most often an "A" student is also a good research student. We have encountered two common types of good students: one that truly enjoys scientific work and challenge – a career in science is perfect for them, and the other for whom this is a transient phase on their way to, usually, medical school. Not all pre-med students fall into "pre-med who lost interest" category. Even though they do not plan on becoming chemists, a large number of them are dedicated to the research project and do their best to get the most out of the experience.

Research can be particularly beneficial to "B students." Occasionally, these students do not perform as well in the class, but they excel in research and in practical laboratory work. It is possible that their preferences and abilities are more suited to tackling actual research problems rather than the general study of abstract concepts. With these students, research can provide additional motivation to excel in their studies and can help them select a future career.

As the students' grades decrease, the "yield" of good research students also decreases. Thus, relatively few of the C students turn out to be good research students. One can

safely say that most of them fit into a category of marginal students. Still, occasionally a C student will do high quality research work and produce very good results. Such students are frequently quite capable of mastering one field of study, but may be highly deficient in others. These students are likely to do better as their studies progress and their field of study narrows and may be reasonably successful in a graduate program. For these students, undergraduate research may be highly beneficial as it may help them identify a field that they are likely to be successful in.

One should spend the most time with the best students and the least with the marginal ones. This may appear to be counterintuitive as marginal students are the ones who need help while good students are doing fine. However, if the best students put in much effort and show the most promise, they should be reciprocated and given adequate attention. While marginal students should not be neglected, no effort on a professor's part will make a difference in the quality of work with an unmotivated student. The research project will be successfully completed only if the professor does all the work, and that would be quite all right with the student in question. On the other hand, additional time put into work with a good student may result in publication(s), improved reputation and visibility of the institution, and help place that student into an excellent graduate program

## 5. What is a Success in Undergraduate Research?

While there are some similarities, success in undergraduate research is different from a graduate program where it is usually measured by the number and quality of publications and the level of funding. Getting publications with undergraduate students, and having them give presentations at conferences, is certainly a success, but it is not the only measure. In part, a successful undergraduate research program will prepare student for a graduate work and future career. Thus, in the course of research, the student will learn about the experimental techniques, the use of research instruments, independent thinking, research design and research ethics.

Success in undergraduate research means helping students find themselves and choose the best career for themselves – even if that is not in science. Society will always benefit from a professional who understands and appreciates scientific endeavour. One of the most important measures of success is whether the student is prepared for graduate studies and whether he or she has been able to enrol into a good graduate program.

## 6. Conclusions

A successful research program is a significant asset to an undergraduate institution. Faculty who participate in it are passionate about their work rather than being frustrated and

even bitter. Faculty have flexibility and freedom in selecting research projects and find research with undergraduates to be rewarding. On the other hand, there is always a danger that research program may stagnate or even regress. Thus, it requires constant attention on the part of faculty and administrators. However, the effort and expenses are justified as research accomplishes objectives in education of undergraduate students that cannot be met in any other way. Undergraduate research has a promising future particularly at the institutions that value education and are concerned with future success of their students.

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