temperatures of the environment are within the range required for germination. After dispersal in September, the seeds germinate within a few days if soil moisture is nonlimiting; however, in central Tennessee it is not unusual for the shallow soil in which *B. rotundifolium* grows to be dry for long periods of time in early autumn. If seed germination is prevented by lack of soil moisture in September and/or October, the seeds can still germinate at the normal environmental temperatures that occur in late October and November. Sometime during autumn the soil will be sufficiently moist for a long enough period of time for most of the seeds in a seed crop to germinate.

The only information that we found in the literature pertaining to the germination of *B. rotundifolium* is a study by Kosikova (1960). He found that a 0.03 per cent solution of gibberellic acid on filter paper stimulated germination in darkness at 20 C and 25 C. Seeds soaked in gibberellic acid for two days and then rinsed with water and placed on filter paper moistened with water failed to germinate.

Exposure to low, winter temperatures is not a requirement for flowering in *B. rotundifolium*, and its main effect on plants of this species is merely to slow growth and, thus, to delay completion of the life cycle. Plants grown in a heated greenhouse continued to grow through the winter, and by early to mid-March a number of them had flower buds; by mid-April several were flowering. Flower bud initiation and flowering of plants kept in the greenhouse began four to six weeks earlier than in the field. The fact that flowering began several weeks earlier in the greenhouse indicates that flowering in the field probably is not delayed in spring because of a short photoperiod requirement *per se*.

The winter annual type of life cycle exhibited by *B. rotundifolium* is an adaptation to a climate where a cool, moist season alternates with a hot, dry season. Although central Tennessee receives adequate precipitation throughout the year (USDC, 1965), the shallow soil in which *B. rotundifolium* grows almost invariably becomes extremely dry during summer, especially during July and August. By completing its life cycle in early summer and remaining in the seed stage from July to September, *B. rotundifolium* "avoids" the hottest and driest part of the year.

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UNDERGRADUATE RESEARCH: IT CAN BE DONE IN A LIBERAL ARTS COLLEGE

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ABSTRACT

The experience of the Chemistry Department of Carson-Newman College demonstrates that a liberal arts college in Tennessee can provide undergraduates opportunities to participate in meaningful research. Individual efforts are fitted into an overall research plan so that results published from time to time in standard journals fit together.

INTRODUCTION

Participants in the Wooster Conference on Research and Teaching in the Liberal Arts College agreed that research is beneficial to both undergraduate students and faculty members (Lewis, *et al.* 1959). Many of our graduates have considered participation in research during the undergraduate years an unusual and valuable part of their experience. Nevertheless, college teachers sometimes speak wistfully of research as if it were beyond the realm of possibility in an institution which does not grant Master's or Doctor's degrees. Indeed there are discouragements, but our experience at Carson-Newman may provide encouragement. More than fifty-eight of our students have been recognized as coauthors of publications in the *Journal of the American Chemical Society*, the *Journal of Organic Chemistry*, and the *Journal of Medicinal Chemistry* since 1948. One of our more recent projects which involved the synthesis of compounds for use in cancer chemotheraphy research has resulted in fifty-three publications prior to 1970 at Carson-Newman, and a total of twelve publications of studies conducted in other laboratories on compounds prepared at Carson-Newman (Bahner, 1970).

WHY UNDERGRADUATE RESEARCH?

Scientific knowledge begins as research. The nature, limits, and cost of scientific knowledge can not be realized without research experience. The identification of an "unknown" in the laboratory is actually a very small research project, but lacks the motivation of typical research. Our experience has confirmed the fact that it is possible for many undergraduate students to know the thrill of contributing new knowledge to mankind and having a significant part in a new project that will ultimately meet a basic need.

In the research project the student becomes motivated in a new way as he[1] finds the reason for the technique he has learned. He is brought into closer contact with his teacher and learns from him how to meet disappointments as well as successes, to avoid leaping to conclusions on the basis of inadequate evidence and at the same time to see possible significance of even minor clues. Most of all he catches the enthusiasm of his professor. Certainly one would hesitate to recommend that a teacher attempt to direct research unless he himself enjoys it enthusiastically. Perhaps, sometimes, there are professors who regard research as drudgery because of having been under too much pressure during their graduate school experience. Such a person may discover a wonderfully satisfying new experience when he is working on his own project at his own pace.

We can not provide numerical measurement of the value of the undergraduate research program, but many graduates and individuals who have observed the work of our graduates have stated that the experience was highly valuable in preparing them for their careers. At the same time, those who participate in research pass on to other students something of their own experience.

SPECTATOR EFFORT

Provision should be made for others to observe, through a glass window or otherwise, the research activities. One of our students who went on to obtain a Ph.D. degree at Vanderbilt and is now employed in a responsible position as a scientist said that watching the research team through the door of the laboratory convinced him that research was to be his goal. He is far from being alone; others have gone into such areas as general medical practice with a better understanding of the nature of medical science.

INITIATION AND GUIDANCE

Without guidance, the typical undergraduate is not able to select a suitable topic for research. Either he selects one which is so big that years would be required to handle it, or he selects one which would be a repetition of work already done. The experienced teacher can bring the student to the edge of present knowledge and point out further questions that can be answered by a semester's effort. It is important for the teacher to have a realistic overall plan and to show the student how his contribution will fit into the final picture, like a bit in a jigsaw puzzle.

The student exercises initiative in selecting which of the suggested topics he will investigate and what method he will try first. As he works, he should be encouraged to observe closely and discuss with his teacher unexpected observations and new ideas that occur to him. As he gains experience, he can assume more and more responsibility. The beginners need the watchful eye of a more expert chemist, but even those with more experience benefit from knowing that their progress is being observed with enthusiasm by their teacher. In a number of instances, students who had done research during their Junior and Senior years in college continued it successfully during the summer following graduation while their professor was not physically present. Each day they would mail to him a report of the day's progress and he would respond from time to time. Of course, this method is satisfactory only with the most reliable students and safety requires that there be a faculty member within call to deal with any accident, even though he is not responsible for planning the research activities. In the few cases where there has not been close daily contact between student and teacher, in person or by mail, the results have often been inferior.

THE TIME FACTOR

It is important to protect an adequate amount of the student's time for his research. One good method has been to give academic credit for research at the rate of three semester hours for 153 clock hours of research, the grade being determined by the quality and quantity of work performed. Another method has been to employ students, usually after completion of 3 or 6 semester hours of research for credit, on a sliding pay scale depending on experience and achievement. Only rarely have satisfactory results come from unpaid volunteers working without credit. The reason is that there are so many demands on students' time that they rarely are able to finish what they begin, unless they are able to say, "I *have to* do research today!", when they are called on to donate time to other activities. There have been some fortunate exceptions; for example a young lady donated several hours a day for a few weeks, concentrating her efforts on running melting points for a group of workers. In a few days she became expert at this one operation and, by listening and talking with the other workers, she became a part of the team. Later, she took an advanced degree in another institution and today is a research worker in a leading drug manufacturing company.

[1]As a matter of convenience I use the masculine pronouns, but it must be understood emphatically that many excellent research workers in our college have been young women.

PROJECTS

Our most extensive experience has been in synthesis of compounds for use in cancer chemotherapy studies. A general type of compound is selected; the literature is surveyed for known compounds belonging to the series and methods for their preparation; compounds having the desired structures are chosen; the intermediates and finally the desired compounds are prepared. In some instances, the compound sought is already reported in the literature so that melting point and similar criteria serve as adequate proof of identity, but more often the compounds are new, so that purification, analysis and other means of characterization, such as infrared spectrum determination, are required. When several proposed compounds appear equally likely to be useful, we seek to make first the one most easily prepared, then use this experience in preparing the more difficult ones. When reports of biological activity come back from the National Cancer Institute or other testing laboratories analogs of the most active compounds are designed and synthesized.

TEAMWORK

A team approach is used and individual responsibilities are assumed by different members of the team. For thoroughness, one worker searches the literature and later another rechecks it. Preparation of an intermediate by a method in the literature may be one student's task, converting the intermediate into a new compound another's. Often the methods in the literature do not produce good yields of the desired products and it is necessary to compare several methods of synthesis and modify one of them until satisfactory yields are obtained. After the compounds are made one student may examine the absorption spectra of a series of related substances.

APPRENTICE SYSTEM

If each chemistry major who wishes to do so is permitted to undertake a research project it may not be practical for the professor to provide as much guidance as each one needs during the first weeks of his effort. A solution to this problem has been found in an apprentice system. Each beginner is assigned to a more experienced worker who can "show him the ropes". Sometimes the beginner repeats a synthesis already run by his mentor, then proceeds to a new synthesis along a similar line. This approach has been successful for high school students in a summer institute, guided by college students.

The cost of apparatus and chemicals has to be taken into consideration in selecting projects. After some measure of success has been achieved, grant funds help with this problem and also with employment of more experienced workers, but usually it is necessary to begin without such aid.

FINANCES

Money is not always easy to obtain. The teacher will be forced to provide his own funds at times. In one case an accident which put the professor's leg in a cast provided a small amount of cash from an accident insurance policy which could be used to pay a student research assistant. After several years, a chemical manufacturing company purchased patent rights at a price which amounted to above 35¢ per hour of the time the professor and his paid assistant had devoted to the investigation. Later, various groups such as the American Cancer Society, the National Cancer Institute, the Damon Runyon Fund and the Research Corporation provided very helpful grants. One thing we have learned about funding is that its ups and downs are not necessarily parallel to the progress of the work. One week a letter came from the screening laboratory saying that the compound just tested was the most promising one we had submitted. A few days later a letter from the foundation notified us that our support was being terminated immediately.

PROFESSIONAL GROWTH

One problem of the teacher in a small college is the lack of contacts with other scientists working in the same area. This need has been met by a combination of approaches: the attendance at two or three national or regional scientific meetings each year, participation in local section scientific meetings, such as ACS, Sigma Xi and TIC; at least one visit a year to a research center such as the National Cancer Institute or Sloan-Kettering Institute for Cancer Research; working an average of half of the summers in large research centers; and frequent visits to large scientific libraries. Consulting work from time to time is also of great value in keeping in the forefront of developments and gaining fresh viewpoints.

SAFETY

Safety in the organic research laboratory is a matter of critical importance. For example, large volumes of hydrocarbon solvents are required for recrystallization of many of the compounds that have been synthesized. Since the vapors present both fire and explosion hazards no flames at all are permitted in the laboratory where the recrystallizations are being run. When a student in the laboratory refused to heed the no smoking rule, the research students had to remove him bodily from the room before he could be convinced that the rule was not just an intrusion on his personal liberties. In spite of good ventilation and great care, a container of hydrocarbon which a student was carrying did catch fire. Fortunately, others in the room came to his assistance immediately and he was not seriously burned. But these incidents emphasize the necessity of thorough safety indoctrination, and of requiring that a student never work alone when dealing with hazardous materials or equipment.

PUBLICATION

"Publish or perish!" In the original sense the old slogan does not apply to most professors in four-year

colleges. The number of publications does not make much difference in the salary check. But it is true that if new information is not published it does perish. A sustained effort should be made to see that the topics chosen and the quality of work done are appropriate for publication and that the information gathered is actually published and not allowed to gather dust in some forgotten notebook. Preparation of the publication is a necessary part of productive scholarship and must not be neglected. The student should participate by preparing a summary of his work in form readily worked into the finished paper, even though the professor may have to weave the substance of several such reports into a single publication. The teacher may not receive any financial reward for publication of the paper, but the student often discovers later that having his name appear as coauthor on a report in a standard scientific publication helps him in getting a position. The publicity benefits the college as it comes to be known for its scientific activities. The Collegiate Division of the Tennessee Academy of Science and some other scientific society meetings provide opportunities for the undergraduate to present the results of his work orally and provide valuable experience in explaining and defending his conclusions.

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EFFECTS OF COUMARIN UPON PLANT GROWTH AND DEVELOPMENT

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ABSTRACT

Coumarin, the lactone of *cs-o*-hydroxy cinnamic acid, is widely distributed in plants, and is especially abundant in tonka bean, *Dipteryx odorata*, and the sweet clovers *Melilotus alba* and *M. officinalis*. It inhibits growth of bacteria, and has a fairly low toxicity to higher animals and man. Its cytological effect is that of a spindle poison, producing C-mitosis. It inhibits longitudinal growth of roots, but augments lateral growth, producing swellings. It inhibits germination of a wide variety of seeds.

Tracer experiments have demonstrated that it is biosynthesized via the shikimic acid pathway, with phenylalanine and *trans*-cinnamic acid as intermediates. One pathway then involves *cis*-cinnamic acid and *o*-coumarinic acid, an alternate route consisting of *o*-coumaric acid, *o*-coumaryl-β-glucoside, *o*-coumarinyl-β-glucoside and coumarinic acid.

Coumarin has a great number of physiological effects upon plants, including decrease in the permeability of tissues to water, inhibition of a number of enzymes, interactions with auxin and other plant hormones, and decrease in the biosynthesis of cell wall materials. Despite numerous investigations of its effects upon plant growth and development, it appears that its primary effect is not known.

INTRODUCTION

While coumarin the lactone of *cis-o*-hydroxy cinnamic acid (*o*-coumarinic acid), has been the subject of numerous review articles, including those of Sethna and Shah (1945), Dean (1952), Reppel (1954) and