A Goal-oriented Approach to Laboratory Development and Implementation

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1 INTRODUCTION

Curriculum committees of the Association for Computing Machinery (ACM) have recently advocated the use of laboratories in computer science curricula. There is much interest in laboratories and as with any "popular" pedagogical device there is the rush to adopt first and analyze later. Adding laboratories to a curriculum does not automatically make it a better program and, in fact, can make it worse if there is not a clear vision as to the goals that will be achieved by the addition. In this paper we will present a goal-oriented approach to the creation and implementation of laboratories in the undergraduate computer science curriculum. We will summarize a number of issues and concerns discussed during numerous workshop activities and will present ideas we have found successful in implementing closed labs at our respective universities.

In the next section, a few terms will be defined. In section 3 we will discuss issues regarding the goals for closed labs and some of their implications. In section 4 we will discuss methods of evaluation and lastly, in section 5 guidelines for the development and implementation of these closed labs will be presented.

2 TERMINOLOGY

Many computer science departments are adding both closed and open laboratories as additional instructional techniques. Due to the nature of the methodologies in computer science, we have a richer variety of possible models for structuring laboratory instruction than the natural sciences. These various models are defined by a few key variables.

Closed laboratory sessions refer to sessions in which an instructor is available to provide immediate feedback about the required work. Open lab sessions refer to the laboratory assignments which are completed by the students without supervision or immediate access to assistance.

Scheduled laboratory sessions are defined to take place at a specific time with a fixed duration. This is in contrast to an unscheduled laboratory session in which an assistant is available for an extended period of time and students are free to show up during that time and work in a supervised environment. Scheduled laboratories are often used to facilitate team work among a group of students.

Structured laboratory activities are provided through a detailed, step-by-step procedure. This approach is in contrast to the open-ended assignments given by many instructors.

Each of the models, arising from the various permutations of these three attributes, has its advantages and disadvantages. For example, the scheduled session requires all students to be in the same place at the same time making small group work possible. This can be particularly important since economics is forcing overall class size to increase. On the other hand, unscheduled, "drop-in" laboratories provide the student with maximum flexibility in scheduling their time. None of the models should be used to the exclusion of the others.

The discussion in the remainder of this paper focuses on closed, scheduled laboratory sessions that use structured laboratory experiments to guide the student's learning. We believe this model complements the existing instructional techniques to provide the means for meeting the educational goals that were not otherwise being met.

While our focus is on closed scheduled laboratories in this paper, that is only one facet of an effective instructional approach. A complete learning context includes the following types of activities.

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- "Lecture" sessions which are conducted at a conceptual level and which provide a context for each concept.
- Closed laboratory sessions in which structured procedures are followed to experience the concepts at a more concrete level.
- Open laboratory assignments in which the student has greater flexibility to exercise their creative talents.

These three techniques together support a wide range of learning modalities and greatly increase the number of students who will learn a particular concept.

3 ISSUES

3.1 The relationship between goals and laboratories

Laboratories are being added to curricula for a variety of reasons. Some are seeking increased retention of students while others are interested in increased retention of material. Laboratories should be added to the instructional repertoire in support of specific, and sometimes expanded, sets of course and curriculum goals.

- **Goal: To give students additional modes of learning to supplement the standard, lecture format.** If the lab activity is designed properly and utilized in the maximum extent, students will be given an opportunity to supplement information learned in the classroom by participating in activities drastically different from the ordinary teacher/lecture concept. Obviously, whatever meaningful experiences we can give our students in regard to the concepts involved in computing, we add to the depth and breadth of the student's understanding of the concept. Students actively participate in concepts rather than merely hearing or reading about these concepts. The closed lab environment requires that students participate in certain activities and when and if problems occur, an instructor will be readily available to assist.
- **Goal: To provide opportunities for group learning and for building skills at team work.** This means that students will participate in group work and group interaction to solve a problem or conduct an experiment. Group learning helps to create a form of peer pressure which stimulates students to achieve a higher understanding of the concepts involved and it fosters the team concept which reflects activities "on the job" . Concerns about evaluating the work done by a team are often misplaced because the wrong measures are applied. Attempting to attribute original work to each of several members of the team misses the point that the work is the product of a team effort. How well the conceptual material is mastered will be revealed on later examinations. The laboratory can focus on process goals such as the method by which the group made decisions and resolved disputes.

  Collaborative learning emphasizes cooperative efforts among students to complete a project [3] [4]. The research of R. Sabin and E. Sabin, which conducted collaborative learning experiments in CS1 by comparing achievment levels of a collaborative learning class and a control (non-collaborative) class, indicated higher achievement levels for the collaborative learning class. They also noted other advantages to this methodology such as "students became acquainted more quickly" and "the atmosphere of the classroom was friendlier". [5]
- **Goal: To reinforce and give a discipline-specific context to written and oral communication skills.** Oral communication is necessary since students will be working in a group environment and written skills can be encouraged by requiring written summation reports. Critiques of a presentation to a small group in the laboratory can be carried out in a non-threatening way by peers. We use a checklist approach to guide students, who are not trained, in providing feedback to each other.
- **Goal: To provide for an expanded set of topics in the core undergraduate computer science courses.** We have used the laboratory setting as the vehicle for introducing students to the breadth of the computer science discipline in the first four courses. Using techniques such as exploratory labs, described in the next section, we have provided surveys of sub-areas within computer science and guided students in exploring basic concepts in these areas. Labs can also be used to promote the integration of skills learned in other courses such as mathematics or statistics into the curriculum.
- **Goal: To establish a sense of community among the students and faculty.** Since closed labs can be designed to encourage cooperative efforts among individuals, students can quickly begin to feel a certain loyalty to the department. This is especially helpful in CS1 where beginners in the field tend to feel isolated from the department because of their inexperience in dealing with the faculty and other students in the discipline. This sense of community is also a positive factor in retaining minority and female students.

The nature of these goals must be considered when evaluating the success of laboratories. The small amount of formal evaluation that has been carried out on the effectiveness of laboratories has used traditional examinations over the traditional conceptual goals of the course. This does not evaluate the effectiveness of the laboratory as much as the course as a whole. If building effective team skills is a goal, a paper and pencil based evaluation process is not a valid measure.

3.2 Goals and types of laboratory exercises

Naps[2] lists four categories for lab exercises. We have related these to the types of tactical instructional goals that they support.

1) Discovery Labs - This type of lab exercise addresses a goal in which we are attempting to broaden the curriculum through the lab activities.

2) Improvement Labs - Goals which relate to developing skills at analysis and comparative techniques are addressed by this type of lab.

3) Comparison Labs - Goals that address analytic and comparative skills are addressed by this type of lab.

4) Reinforcement Labs - Goals that relate to increased retention of concepts are addressed by these lab activities.

Some additional types of lab exercises that we have identified and used include:

1) Exploratory Labs - These lab activities are constructed specifically to meet the goal of exploring the breadth of the computer science discipline.

2) Skills Labs - Goals to achieve proficiency with the basic tools and techniques of our discipline are addressed by this type of exercise.

3) Methodology Labs - Goals of learning methodologies for solving problems in computer science are satisfied by this type of exercise.

The laboratory curriculum for a course should be a blend of these lab types. This provides for meeting a range of instructional goals and maximizes the potential for learning for the most students.

3.3 Desirable attributes of lab exercises

We have developed and implemented many closed lab assignments and have noted the following suggestions which have been successful for us.

- Closed lab activities should NOT involve extensive programming. Programming-intensive activities should be reserved for open lab assignments. The productivity of professional programmers should provide some indication of the extremely small amount of code that we should expect a student to complete in a 2 hour session.

- Closed lab activities typically may involve source code, but this code should be provided to the student. Students may be asked to make minor changes in the code for experimentation, comparison, or improvement. Reading code and reverse engineering it to gain an understanding of its design is another appropriate use of code within the closed lab.

- Collaboration should be encouraged. As we have indicated previously in this report, collaboration will result in many benefits. Other benefits which we have observed in our classrooms include: a) students become more closely associated with others in the field, thus producing a built-in mentoring mechanism; b) peer pressure tends to increase the desire to perform well in a group and c) students are more likely to ask questions when working with a small group of their peers.

- Labs should be designed in such a way that the majority of the students will finish during the specified lab time. The closed laboratory activity may be closely coordinated with another open lab assignment (as seen at the University of Virginia[6]), but there should be an identifiable product that can be completed within the scheduled time.

- Many labs should be "interactive" in nature. These assignments will typically involve activities where students try short experiments and record the results of each experiment. For example, a typical lab of this nature may involve the validation of the basic theoretical relationship between the size of a hashing table and the number of clashes.

- Many labs may not involve the use of the computer in any respect. For example, ask students to bring a deck of cards to the lab (or provide students with the cards) and conduct experiments on parallel processing where each student in the group will represent a separate processor and the cards will represent numbers which need to be sorted.

- Many labs, if not all, should require an analysis of the procedures executed and the data collected during the session. Structured lab activities should meticulously guide students through various exercises and allow the student at the end of the lab to analyze the result of the exercises and "discover" the underlying concepts.

- Use of tools, such as word processors, spreadsheets, and statistical packages, should be encouraged. Often students in the computer science field are not given sufficient opportunities to learn and to actually use software packages.

- Structure lab experiences using a prelab, in-lab and postlab concept. Prelab activities involve short activities which are to be completed by the student before the actual closed lab begins. This may involve, for example, accumulating information or knowledge which will be needed in the lab. Postlab activities provide exercises that should be completed after the closed lab experience.

4 EVALUATION

4.1 Student evaluation

There are several approaches to this problem. Most agree that the main grading criteria should focus on participation and technique rather than specific results. Experiments will usually have several alternate paths depending on selected inputs and therefore, the results may vary. The team environment also makes it less appropriate to evaluate individual results.

- The evaluation should be appropriate to the activity. In team efforts not everyone will experience every phase of the activity. The desired result may be that they have cooperated and coordinated, not that they understand every facet of the resulting system. The evaluative activity may be a checklist that each student completes in a self-evaluative exercise.

- The weight given the laboratory assignments should reflect their role in the course rather than how reliable the instructor views the grades. Some instructors weigh the closed labs grades more heavily toward the final grade than the open lab grades since students are working under a closely supervised environment in closed labs. This ignores their relative contribution to the course goals.

- The laboratory instructor should include in the evaluation their observations during the experimentation. This is critical if group interactions, leadership and other factors are part of the goals for the laboratory. These factors can not be evaluated from the lab reports. A checklist can be used to maintain consistency in the criteria of the evaluation.

4.2 Evaluating the overall role of laboratories

As we previously stated, the evaluation should be tied to the goals for the laboratory component. There are several sources of information for evaluative purposes.

- **Students registered for lab courses** - Students in every section of a closed laboratory complete an end-of-semester evaluation form. We conduct exit interviews with all graduating seniors. It is possible to assess some of our goals for the laboratories from this information.

- **Lab instructors** - The course faculty meet each week with the lab instructors. The information flow provides feedback during the semester. It is important to note that a number of our graduate teaching assistants have been recognized at the college level for the quality of their teaching.

- **Faculty** - Faculty in the department evaluate the effectiveness of the laboratory activities both within the context of the lab-based course and from the perspective of the skills needed for the upper division courses. It was through this last perspective that we discovered early in our implementation of labs that faculty were reducing the number of open laboratory assignments and programmin skills were declining as a result.

This evaluative process is not intended to answer the question of whether the lab approach is better than approach **X**. It is intended to address the question of how effective are our laboratory exercises, which should be improved, and how can they be improved.

5 GUIDELINES FOR DEVELOPING LAB EXERCISES

The first step in developing a lab exercise is to establish the goals for the experiment. These goals should be directly related to the overall goals of the course. The goals for the lab should determine the specific topics to be addressed in the lab exercise.

The second step is to select a series of activities that will contribute to the student learning the selected concepts. The activities should take advantage of the special environment of the laboratory. For example, at Clemson University, we have used a lab activity in which students simulate the processors of a multiprocessor system and perform tasks such as sorting a deck of cards as described earlier in this paper.

After goals, topics, and activities have been established for each lab, the detailed procedure is developed. The write-up should include the following subheadings: Goals, Background, Materials Needed, Procedure, Analysis of Results, and Conclusions.

1. Goals: Students should be given a clear indication of the purpose of the lab at the beginning so that they have some feel for the nature of the lab and what will be involved in the activities during the lab. The goal statement should also establish the importance of the lab activity to the overall course.

2. Background: Many labs may involve materials and concepts not previously introduced to students. Therefore, a portion of the lab write-up and the instructor's introduction should be devoted to the clear and very specific introduction of these ideas and concepts.

3. Materials Needed: A listing of all materials needed for the completion of the lab should be demonstrated early in the lab. For example, if students will be utilizing files or other software during the completion of the lab, this information should be clearly stated in the written exercise..

4. Procedure: Clear and specific instructions should be given to guide students through the lab exercise. These instructions should be active in nature to allow the students to participate in numerous activities. We found in our closed labs that students perform better in this portion of the lab if they are asked to carry out numerous short exercises. These exercises may be devoted to using the computer in some way, responding to short questions, or actively participating in some type of physical activity (walking to the front of the room, for example!). Laboratory curricula developers at the University of Virginia break the procedure into a set of short exercises. After each set, the student must get the signature of the lab instructor before proceeding. This further enforces the sequence of steps through the procedure.

5. Analysis of Results: The students should be guided by a series of questions through an analysis of the results of the activities or experiments. Students should then be encouraged to draw conclusions or formulate ideas regarding the topic. For example, exercises related to parallel processing may encourage students to examine results from the parallel computations and analyze exactly why some activities which were completed in parallel required more time than a similar sequential activity.

6. Conclusion: A brief summary related to the goals and ideas expressed in the lab should conclude the description of the lab exercise. The conclusion reiterates the goals and relates each activity to a specific goal. We also usually include additional readings in this section.

6 CONCLUSIONS

We have had an extremely successful introduction to the closed lab concept at our universities. Based on a study conducted by Thweatt [7] at Middle Tennessee State, we see the benefit of closed labs as related to its effectiveness in regard to test scores. However, as previously mentioned, there are many ways to measure success. At this time, we can only measure our success based on student comments, and we hope in the future to perform retention studies and other longitudinal studies.

At Clemson, we have experienced a broadening of the curriculum and a broadening of the skills developed by students. We have applied the lab concept to stand-alone labs that teach specific language skills, in a laboratory format. We have also used the laboratory portion of the core courses in the computer science major to introduce the breadth of computer science as a discipline very early in their curriculum. In each of these cases, the lab approach was used because it was the best way, in our opinion, of achieving our goals.

Many schools around the country are implementing laboratories as a part of their curricula. This can be a positive addition if the goals of the laboratory component are clearly delineated and carefully coordinated with the activities of the other components of the course. Adding labs because "everyone else is" or because "ACM says to" will never produce results that will be sufficient to justify the effort. Those departments that approach the change in a thoughtful and systematic manner will be rewarded.

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