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Abstract

A small, programmable calculator (HP-55) was used to introduce fundamental concepts of the structure and operation of a digital computer and of assembly language programming. This hands-on approach was used in a course offered during the Fall, 1975, semester at Purdue University. This paper describes the motivation for using such an approach, the results of a student survey, and the author's evaluation. Overall, the approach seems to have stimulated student enthusiasm and resulted in a lower than normal drop-out rate for the course.

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1. Introduction

This paper describes a different approach to teaching a college course in computer organization and assembly language programming. The approach uses small programmable calculators to introduce some of the concepts which are fundamental to the course. This introductory portion of the course is intended to provide students with a better grasp of the structure and operation of a digital computer. The course then continues with the more traditional approach of teaching assembly language programming for the computers which are available locally.

We proceed by giving a brief section on the motiviation for using this technique. A description of the relevant portion of the course material follows. The paper then presents a summary of some statistics detailing usage of the calculators and student reaction to the approach. The conclusion consists of the author's evaluation of the approach and of programmable calculators which are currently available.

2. Motiviation

In spite of the increasing use of high level programming languages, college students in several disciplines still have a need to learn to program a digital computer using the assembly language for that computer. This need arises from at least four sources:

a) Assembly language is a useful vehicle for describing and teaching the structure and operation of a digital computer;

b) Some computer applications have stringent performance and/or space requirements which cannot be met by the machine code produced by existing compilers;

c) **Usable high-level languages (such as PL/1, FORTRAN or COBOL)** may not be available with some computers; examples of this include some minicomputers, microprocessors, and laboratory and other special purpose computers;

d) A few programming applications require features not present in an available high-level language.

Because of these needs, assembly language programming is an important component of a balanced curriculum for students in Computer Sciences, Computer Design and Engineering, and other areas which make extensive use of digital computer systems (1).

The Computer Sciences Department of Purdue University offers one course, entitled Assembly Language Programming (CS 300), which provides instruction in assembly language programming. This course presents the subject via a combination of lectures and programming assignments which require the students to write and debug programs for the CDC 6500 in use at Purdue. These assignments are a critical part of the course, but they are also a stumbling block to the successful completion of the course by many students. It is apparent that there are students who manage to complete the programming assignments, at times with great difficulty, but who fail to grasp the key concepts of data, storage, registers, instructions, and sequencing.

In an attempt to improve student comprehension of these key concepts, we proposed using a programmable calculator to introduce CS 300 students to digital computers. We felt that by being able to interact directly with the calculator, students would be able to visualize, with better comprehension, the structure and operation of a stored program device.

The Faculty Grant Program for Instructional Development and Innovation, Purdue University, supported the purchase of three Hewlett-Packard HP-55 programmable calculators for use in CS 300. During the Fall Semester, 1975, one section of CS 300 was taught using these calculators to introduce students to a digital computer. In general, this approach was well received by the students, and we plan to use this approach in subsequent versions of the course.

3. Course Material and Physical Arrangements

The faculty grant program at Purdue funded the purchase of three HP-55 Programmable calculators, (at $395.00 ea.), three Security Cradles (at $25.00 ea.), and two supplemental manuals (3,4). An evaluation of these calculators and alternatives is presented in a later section. The new course was taught in the Fall semester, 1975, to a class consisting initially of 28 credit students and two audit students.

At the onset of the course, there were two problems: documentation and management of the calculators. The documentation problem was partially solved by refering students to the Owner's Manual (2), (one per calculator) and partially by having the instructor prepare handouts which presented new material and tested (via short homework assignments) student comprehension.

Managing the calculators was finally solved with the cooperation of the Mathematical Sciences Library. The M-S library agreed to supervise use of the calculators, thus making them available a total of 87 hours per week (261 calculator-hours per week). The use of the calculators was restricted to a work room behind the main desk in the library and was permitted only upon surrender of the student's passport (University ID Card) during the period of usage (see Appendix A). We are quite pleased to report that

there was no damage to any of the calculators and that all calculators were intact at the end of the three week interval of use. We had heard "horror stories" regarding similar situations with very unpleasant outcomes.

The calculators were "plugged into the wall", that is we did not use the battery power feature. The Security Cradles, which are metal frames into which a calculator can be inserted and then locked in place, served two useful functions:

(1) A cradle makes the unit large enough so that it is not easily hidden, and

(2) A cradle prevents access to the battery pack and the power cord, thus prolonging the life of both.

A cradle can also be used to bolt the unit into place on a table or to attach a tethering cable. We chose to lock up the units when not in use and therefore did not use these anchoring features.

The course began by introducing students to an HP calculator and, in particular, to the Reverse Polish Notation, RPN, used on these calculators. The 20 data registers were discussed. The students were then asked to write a Fortran program to compute the average and standard deviation of a string of input numbers and then to devise a sequence of HP-55 keystrokes to accomplish the same task (without using the $\Sigma+$ key). Next the programming feature of the calculator was described as a mechanism for recording a sequence of keystrokes. Conditional and unconditional branching had to be used if truly automatic operation was to be achieved. The 20 data registers help teach the concept of storing and retrieving data and the important distinction between the name

(address) of a register and the contents of a register; both are numbers but the context determines their interpretation.

Programs (sequences of keystrokes) are entered into the 49 - step memory of the HP-55 and then can be executed, modified, and debugged. To emphasize these ideas, the next assignment was to write and debug a program which found a positive root of a function using the bisection method. This method, while not terribly efficient, has two properties: 1) it is not given in the HP-55 Mathematics Programs document (3) and 2) it is complicated enough to tax the student's abilities, in particular to fit the program into the 49 steps available. (It can be done if the function is simple enough).

A third assignment required the students to write and debug the following routines: MOD(N), ABS(X), FRACT(X), INT(X) and MAX(A,B,C).

At this point, the course abandoned the calculators in favor of a simulated MIX computer (5) and then the CDC 6500 computer, along with COMPASS, which is the assembly language for the 6500 (6,7).

During the last month of the semester, a term project was assigned. This project required the students to write a COMPASS program which simulated the operation of a slightly modified HP-55. The first part of the term project implemented an RPN calculator; the second part added a programming feature.

We feel that the primary function of a course like CS 300, is to teach students about the structure and operation of digital computers. Concepts of assembly language programming are important but secondary. By organizing the course around three computers (HP-55, MIX, CDC-6500), we thoroughly cover the primary topic. This term project, writing a

computer simulator, is an effective way of tying together the primary and secondary topics. The HP-55 enables students to become very familiar with a simple computer, a familiarity which will hopefully be useful in future topics dealing with other computers.

4. Student Usage and Student Opinion

This section considers two important topics: usage of the calculators and student reactions. As stated earlier, the three HP-55's were made available through the Mathematical Sciences Library. This seemed to be the best way of supervising use of the calculators and also making them easily available to the students. Alternative schemes, such as making them available through the departmental office, failed to meet our objectives of having supervised use and yet achieving high levels of availability.

During the three weeks that the calculators were used (Aug. 28 - Sept. 20), the calculators were available 3 x 261 calculator-hours. Of this, they were used a total of 213.5 hours in 200 separate usage periods. The student sign-out records were used to compile data describing the usage of the calculators. These are summarized in Figures 1, 2, 3, and 4.

We also sought out student reactions to the calculator-based approach. On October 7, 1975, a questionnaire was used to try to determine student opinions. The questionnaire, with the responses tabulated, appears in Appendix B. We might point out that there are discrepancies between the number of times each student used a calculator as determined from the sign-out record (Figure 3) and as determined by student responses to the questionnaire. The questionnaire was answered at the beginning of the section of the course

using COMPASS. It should also be noted that a few students had their own calculators (both HP-55's and HP-25's) and these students did not answer some of the questions.

The responses to the questionnaire can be summarized as follows:

1) 97% of the respondees found the arrangement with the library to be satisfactory.
2) 31% of the students experienced no delay in obtaining a calculator; when a delay was experienced, it was usually in excess of 20 minutes (Figures 5 and 6),
3) The typical student (the mode for question 3) used a calculator 8 times, approximately 30 minutes per session.
4) When a student used a calculator, he
   a) Had a program already worked out (87%)
   b) Spent 3 minutes or less keying in a program (90%)
   c) Found programming the HP-55 to be easy (29%), fun (32%) or OK (21%)
   d) Found debugging an HP-55 program to be tedious (29%) or OK (36%).
   e) Thought the instruction in using the HP-55 was adequate (87%) and the manual was helpful (90%).
   f) If a student needed assistance in using the calculator (40%), he usually turned to the manual (33%).
5) Nearly all of the students had used a calculator before (93%); 57% had used some HP calculator before.

6) Regarding the course, the respondees found:

   a) The second assignment (roots by bisection) was interesting (37%), hard (40%), tedious (23%) and fun (70%),

   b) The third assignment (ABS, INT, FRACT, etc.) was interesting (57%), easy (20%), hard (17%), and fun (17%).

   c) Using the HP-55 helped in grasping fundamental concepts (about 73%),

7) In summary, the students recommended using a programmable calculator in future versions of the course (87%), and they suggested spending the same amount or less time on the calculators (77%).

The students seemed to like this section of the course, but they definitely were ready to move on to advanced machines (like MIX and the 6500).

5. Evaluation

In an evaluation of an instructional technique, there seem to be two major components: a statistically based evaluation (objective) and a subjective evaluation based on the integration of the objective one with opinions from some observers. In our case, the statistical evaluation (presented in the preceeding section) consisted of usage data and a summary of student opinions. In this section, the subjective component of the evaluation is presented. It must be remembered that the evaluator (the author) was also the proposer; thus the opinions may be biased toward a successful outcome.

The calculator-based introduction was proposed in an attempt to improve student visualization of a computer, its operation and its structure.

The hands-on use of a computer was an important part of learning about computers a few years ago. Today, with the advent of large-scale centralized systems, students are denied hands-on use. Minicomputers and microprocessors can be used to make hands-on computing available. However, they tend to be expensive and difficult to use. The recent appearance of small, inexpensive programmable calculators offered an alternative approach for offering hands-on computing. We felt that by offering a short, introductory phase of an assembly language programming course using programmable calculators, we could get students off to a better start.

We tried out this approach in the Fall, 1975, semester, and student reaction implies that we have succeeded.

In addition to the statistics noted in section 4, we can point out that the class began with 28 credit students and two auditing students. Of these, three students (4%) dropped-out prior to the end of the course. This compares with about a 20% drop rate experienced in previous offerings of the same course, taught by the same instructor.

We plan to offer this calculator-based introduction to all three sections of CS 300 next spring. We will probably devote only about two weeks to this (as compared to three weeks this fall). We would like to acquire more calculators, but with judicious scheduling, we should be able to handle the load without too much trouble.

The HP-55 calculators turned out to be reliable and enduring. By using the security cradles and the wall-plug mode of operation, we eliminated (so far) difficulties with battery packs and line cords, which seem to be potential sources of failure. The HP-55 has a digital

timer, which is of absolutely no use in our application. Other than this excess feature, the HP-55 was suitable. However, the HP-25, which appeared after the HP-55's were purchased, seems to be better suited for our application. It is cheaper (by a factor of 2); it does not have a timer; it has more conditional branches; and it has a more efficient way of storing some of the instructions. The HP-25 does have fewer data registers (8 as compared to 20) and fewer functions. We feel that it would be a better device for our application and will consider them if future acquisitions are made.

We originally felt that being able to record and reload programs from magnetic cards would be an essential feature and had hoped to obtain HP-65 calculators, or equivalent. Unfortunately, the amount of funds available eliminated this option, and we went ahead without a program recording mechanism. As it turns out, only short programs are written for these calculators, and, at least in a learning situation, the lack of a program recording mechanism is not a serious deficiency. As noted in section 4, students spent typically three minutes, or less, per session keying in a program.

Grading programming assignments can be a problem. In CS 300, we required the student to hand in a write up, complete with a detailed listing of the keystrokes. Grading these was done by careful examination and by selectively trying out, on a calculator, some of the suspicious pieces of code. Grading such these listings typically required between 5 and 10 minutes per hand-in.

Lack of a suitable textbook is still another problem. This lack requires the instructor to make up notes and assignments on his own, at least during the introductory phase. The notes, lectures, and references to the Owner's Manual seem to provide adequate instruction.

6. Summary and Conclusions

This paper has described an assembly language programming course which used programmable calculators to introduce fundamental concepts of digital computers. The goal of improving conceptualization of the structure and operation of a computer seems to have been achieved. We cannot prove this, but we can point to the results of an opinion survey and the lower drop-out rate. We believe in the value of this approach to the point of planning to use it in future renditions of the course.

We have compared the performance of the students who used the calculators and those who did not (two sections did not use the calculators) during the later portion of the course. There was no discernable difference in the performance of the two groups here.

It appears that using programmable calculators in a computer science department does have a role in the one or two courses which introduce students to digital computers. The value lies in having the students interact with "their computers". Using the HP-55, they can, for example, use the single step function key to execute their programs, one instruction at a time. They can gain an appreciation for the simplicity and low level of detail at which computers operate. They also gain an appreciation for the speed of a computer; the HP-55 seems to operate at about 10 instructions per second.

In the author's opinion, any device which captures a student's interest and stimulates enthusiasm for a subject is probably worth the expenditure of at least a modest amount of resources and effort. Using the HP-55's seem to have done this during the initial trial. If they continue to be used in subsequent semesters, the calculators will demonstrate that they are worthwhile additions to the teaching of Assembly Language Programming.

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List of References

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3. Hewlett-Packard, HP-55 Statistics Programs, Document 00055-90004.

4. Hewlett-Packard, HP-55 Mathematics Programs, Document 00055-90003.

5. Knuth, D. G., The Art of Programming, Vol. 1, Fundamental Algorithms, Addison-Wesley, 1968.

6. Grishman, Ralph, Assembly Language Programming for the Control Data 6000 series, Algorithmics Press, New York.

7. Control Data Corporation, 6000 COMPASS Reference Manual, CDC Publication No. 60279900.

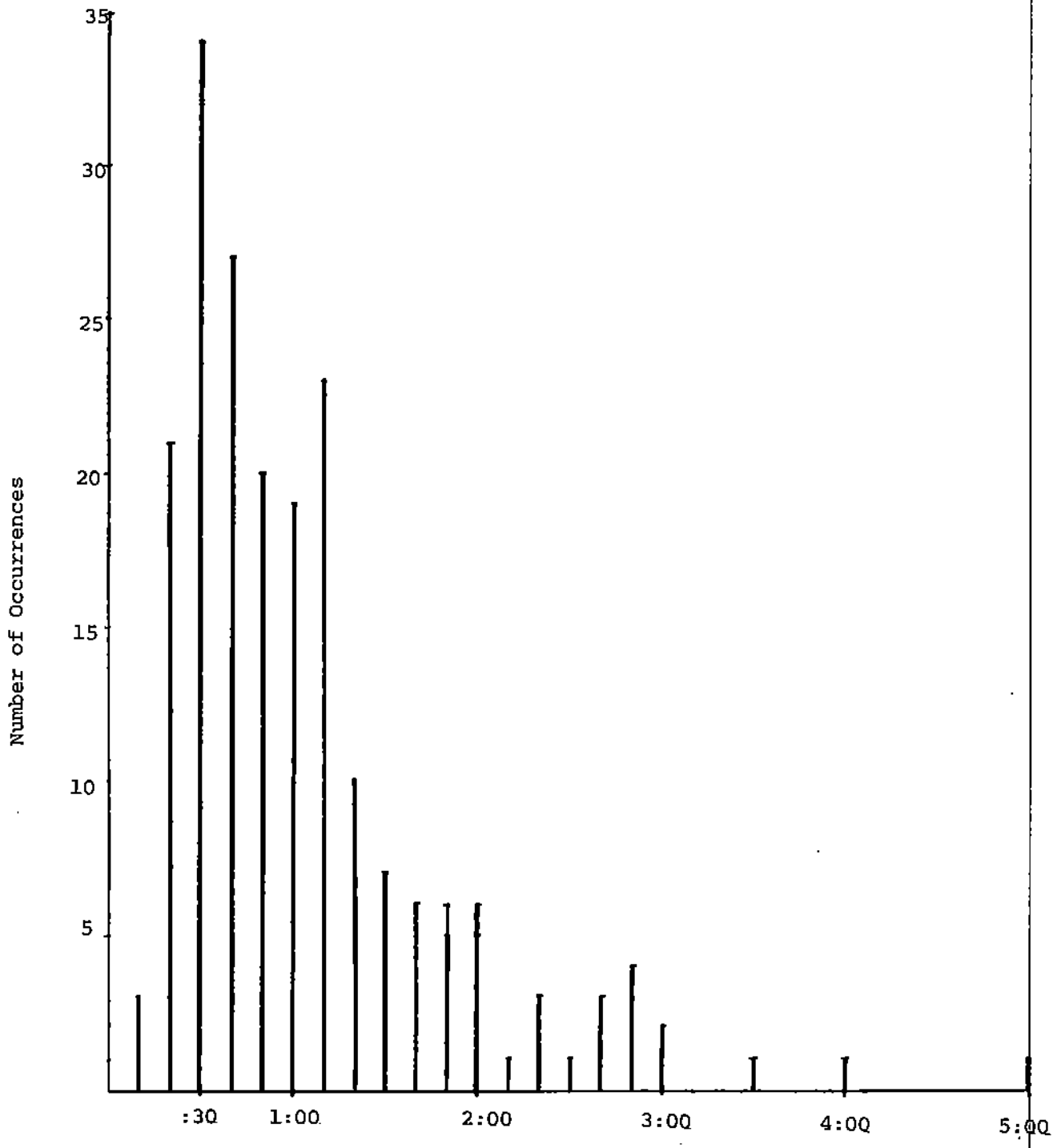


Figure 1

Frequency Histogram for Length of Usage Periods

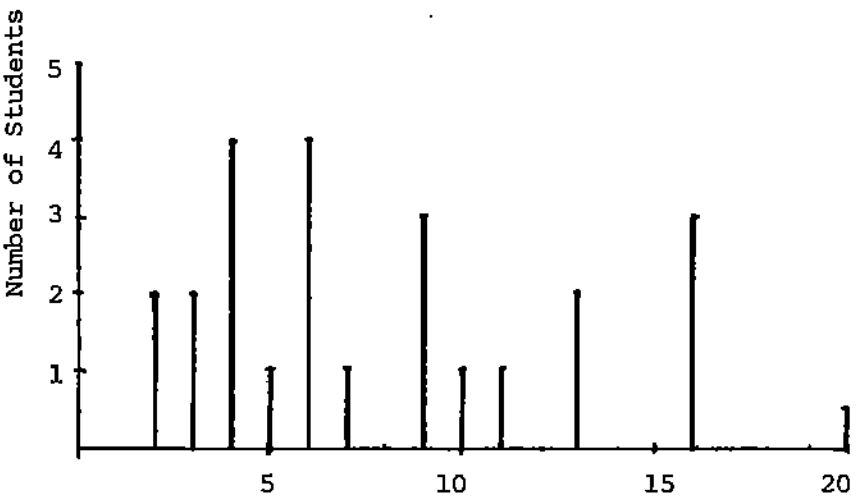


Figure 2

Frequency Histogram of Hours of Use per Student

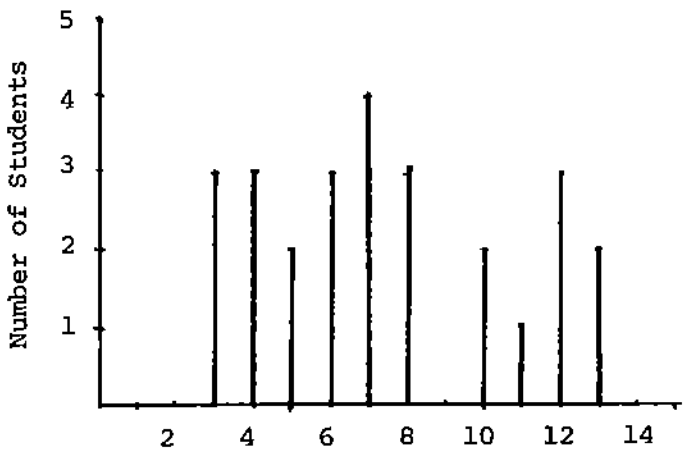


Figure 3

Frequency Histogram of Number of Use-Periods per Student

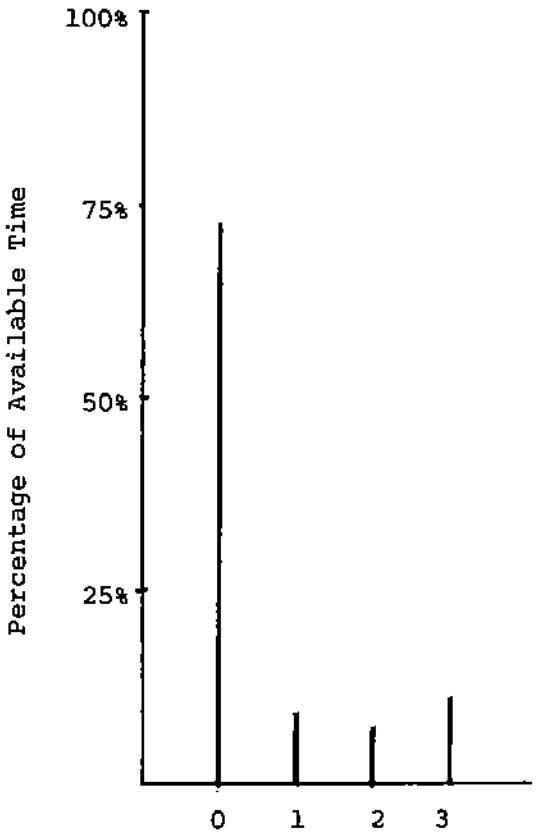
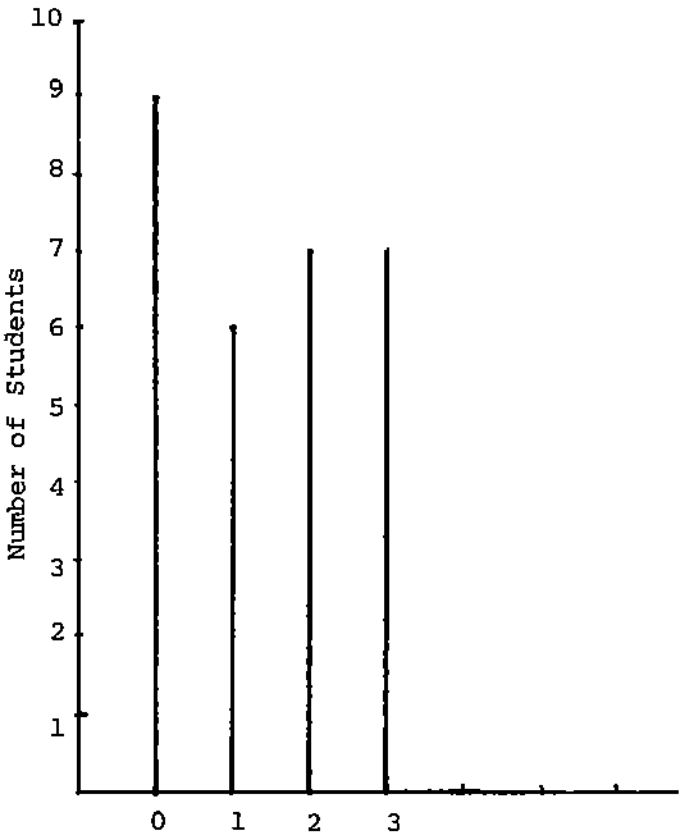


Figure 4

Percentage of Time N Calculators Simultaneously in Use



Number of Times Calculator
Not Immediately Available to a Student

Figure 5

Frequency Histogram of Number of
Times Calculator Not Available

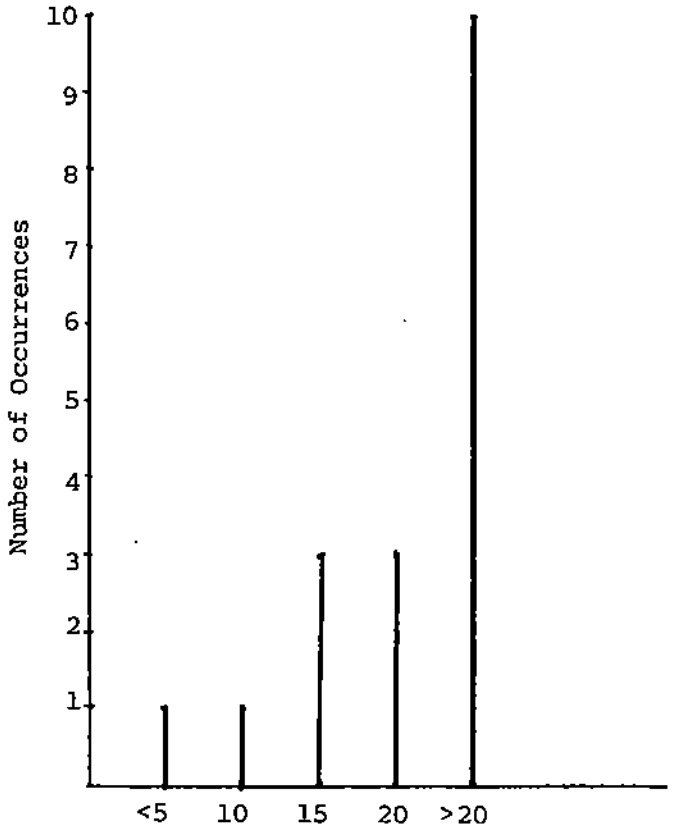


Figure 6

Frequency Histogram of Amount Time Waiting

Appendix A - Notice from Library

Appendix B - Results of Questionnaire

Appendix C - List of Portable, Programmable Calculators

PURDUE UNIVERSITY inter office memorandum

To Students in CS 300, Section 3

From R. L. Funkhouser, Science Librarian

Date 30 August 1975

Subject HP-55 Calculators

Three HP-55 calculators are available in the Mathematical Sciences Library for your use. The manuals are in the library's reserve book section. The calculators may be used on the following schedule:

Monday-Friday	8:00a.m. - 10:00p.m.
Saturday	8:00a.m. - 5:00p.m.
Sunday	2:00p.m. - 10:00p.m.

When you wish to use a calculator, give your passport to the library assistant who will place on the circulation form the number of the calculator to be issued to you. Remember: NO PASSPORT - NO CALCULATOR!! Read the circulation statement giving the regulations for using the calculators and sign your name, the date, and the time. The library assistant will then issue a calculator to you.

The calculators are to be used only in Room 344 of the library. When you have finished using a calculator, hand it personnally to a library assistant who will return your passport and add to the circulation form the time of return. Do not at any time leave a calculator unattended.

R. L. Funkhouser

October 7, 1975
Schwetman

CS 300, Section 3

QUESTIONAIRE

This questionaire is intended to survey the opinions of the class regarding use of the HP-55 calculator to introduce Assembly Language Programming. You do not have to provide your name on this questionaire.

Please circle your selected answer for each question.

1. Did you find the arrangement with the library regarding use of the calculators satisfactory?

yes (28) no (1) maybe

If no, list your objections:

Set time limits during rush times

2. How many times were you <u>unable</u> to use a calculator because none were available?

0	1	2	3	4	5	more than 5
(9)	(6)	(7)	(7)			

If you had to wait to gain access to a calculator, approximately how long did you wait?

less than 5 minutes.	10 min.	15 min.	20 min.	more than 20 min.
(1)	(1)	(3)	(3)	(10)

3. Approximately how many different times did you use a calculator?

0	1	2	3	4	5	6	7	8	9	more than 9
(0)	(1)	(2)	(2)	(2)	(3)	(2)	(4)	(7)	(1)	(5)

4. What was the average amount of time per use?

less than 15 min.	15-30 min.	30-45 min.	45-60 min.	more than 60 min.
(1)	(5)	(16)	(4)	(4)

5. Was the instruction in the use of the HP-55 adequate?

yes	no	maybe
(26)	(3)	(1)

6. Did you need help in using the calculator?

yes	no
(12)	(18)

If yes, where did you usually get help?

a. The instruction manual (10)
b. The instructor (0)
c. A classmate (4)
d. Other:_____

7. Before you went to the library to use a calculator, did you usually usually have a program worked our and written down?

yes	no	maybe
(26)	(1)	(3)

8. Approximately how many minutes did you spend keying-in a new program?

/Less than 1 min./1 min/2 min/3 min,/4 min/5 min,/more than 5 min./
(3) (8) (5) (10) (0) (3) (0)

9. How would you describe programming the HP-55?

easy (8) hard (1) tedious (4) fun (9) OK (6) other:_____

10. How would you describe debugging... the HP-55?

easy (2) hard (5) tedious (8) fun (3) OK (10) other:_____

11. The HP-55 instruction manual was

/ helpful (27) / no help (1) / hard to read (0) / don't know, never looked at it (2) /

12. What features of the HP-55 did you like?

Programmability (9)
Registers (5)
Σ+ key (5)

13. What features of the HP-55 did you dislike?

Only 49 program steps (9)
Insufficient conditional branches (7)
Insufficient storage (5)

14. Did you enjoy programming the HP-55?

15. Had you used any calculator before entering this class?

yes	no
(23)	(7)

16. Had you used any Hewlett-Packard (HP) pocket calculator before entering this class?

yes	no
(28)	(2)

17. Had you done any assembly language programming before entering this class?

yes	no
(17)	(13)

yes	no
(13)	(17)

18. Evaluate the two HP-55 programming assignments:

(1) Roots of polynomial by besection method was (circle all answers which apply)

interesting	boring	hard	easy	tedious	fun	no-opinion
(11)	(2)	(12)	(1)	(7)	(6)	(2)

(2) The functions MOD, ABS, FRAC, INT, MAX assignment was

interesting	boring	hard	easy	tedious	fun	no-opinion
(17)	(4)	(4)	(6)	(5)	(5)	(0)

19. What was the most interesting thing done in CS 300 so far?

MIX (13)
HP (7)
COMPASS (4)

What was the least interesting thing done in CS 300 so far?

HP (7)
MIX (5)
EXAMS (5)
Saturday classes (2)

20. Have you talked to people in the other two sections of CS 300 who are using MIX?

yes	no
(9)	(20)

If yes, did you form any opinions regarding their class and ours?

a. The other classes sounded better (3)

b. Our class sounded better (5)

c. All classes seemed about the same (2)

If there are differences between the classes (answers a or b), are these attributable to:

a. The use of the HP-55? (5)

b. The instructors? (3)

c. Other factors? (1)

21. Do you think that using the HP-55 has helped grasp such concepts as:

a.	Instructions	yes (22)	no	(7)
b.	Fetch/execute cycle	yes (21)	no	(7)
c.	Loops	yes (22)	no	(8)
d.	Conditional branches	yes (22)	no	(5)
e.	Registers	yes (22)	no	(2)
f.	Data storage	yes (22)	no	(6)

22. Did using the HP-55 help you or hinder you in learning MIX?

helped	hindered	
(14)	(4)	(12)

23. Would you recemmend that the HP-55 calculator be used again next semester in CS 300?

yes	no	Use HP-25
(24)	(5)	(2)

If yes, how much time should be spent on it?

a. About the same as this semester (12)
b. More time (2)
c. Less time (11)

24. Please write down any comments you wish to make regarding the class, the instructor, the HP-55, and/or this questionaire.

Appendix C Portable - Programmable Calculators

Hewlett - Packard	Price (Dec. 1975)
HP-25	$195.00
HP-55	$335.00
HP-65 (magnetic cards)	$795.00
Texas Instuments	
SR-52 (magnetic cards)	$395.00
Litton Industries (Monroe Calculator)	
MONROE 344 Statistician	$595.00
MONROE 326 Scientist (cassette tape)	$795.00