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SELF-PACED MATERIALS SCIENCE AT C-MU

Over the past ten years or so, a new method of teaching has been evolving in academic spheres of learning. It has been called by several different names, among them the Keller Plan,[1] Personalized System of Instruction (PSI)[2], and Self-Paced Learning (SPL).[3] Although many variants of the method exist, they all include the concept that students should learn material at their own speed, and hence the methods all provide ways of allowing the student to do this. Invariably, "in person" lectures [4] are replaced by reading assignments, tape recorded lectures or perhaps even video taped lectures.[5]

In this paper the details of the self-paced materials science course that has been developed at C-MU will be presented. Also, the student response to the course as well as some of the various economic factors of the course will be discussed. The paper closes with a discussion of the points of departure that this course has made from the well known Keller Plan.

Overview of the Course

Materials Science at C-MU is taught mostly to freshman and sophomore engineering students. A few non-engineering students take the course, but they are by far in the minority. The goal of the course is to lay the groundwork for understanding the way that materials behave, always emphasizing the relationship that exists between the structure and properties of materials. As such we do not study specific materials (such as Ni-based superalloys) in detail. (We do, however, teach more about metals than about ceramics or polymers.) Nevertheless, the goals are to show how structure (be it micro-structure or bonding structure) controls properties, and to give insight into the various processes we can use to control the structure and hence properties of materials.

The self-paced course is run as follows. The subject matter to be covered is broken up into fourteen units (see Appendix A). Each unit contains a brief introduction to the subject to be studied, a reading assignment drawn mostly from the text, and a set of homework problems. (See Appendix B for an example of a unit).

The students is expected to reac the introductory material and the reading assignment, after which he should do the assigned problems. During pre-assigned hours he may question the student-tutor regarding the material. Solutions to homework problems are available to the students, but before he sees them he must show his solutions to the tutor. When he feels he knows the unit well enough, he takes an exam on it. Typically the exams last 15 minutes (see Appendix C for an example of an examination). If the student obtains 70% or higher he may proceed to the next unit. If he gets less than 70% he must wait one day before taking another examination on the unit. The highest grade he can obtain for the unit is then 70%, regardless of his grade on the second examination.

The student proceeds at his won pace throughout the course with two exceptions:

(a) he must finish 8 units by mid-semester
(b) he must finish the course by the end of the semester.

Exceptions to these rules are possible, but the rules are important to have, as many students do not have the discipline needed to pace themselves. Several students, for example, have been permitted to complete the course in the succeeding semester.

After the fourteen units are completed, the student takes a final examination. His grade is based on the quality of his work, not the quantity of work performed.

Specifics of the Course

The text for the course is Van Vlack's "Elements of Materials Science and Engineering," Third Edition, Addison Wesley (1975). This has proven to be a good text for the course, as it contains many review and discussion questions that can be used by the student to check his progress. The major disadvantage of the text for a self-paced course is its small number of practical illustrations. This in fact is a difficulty in most self-paced engineering courses. The wisdom of the experienced engineer is not as available as in conventionally taught courses. For example, his experience in analyzing structural failures is very difficult to place into a self-paced course. We are currently studying several ways that the student can obtain such information, and we plan to implement them in future self-paced materials science courses.

As can be noted from Appendix A, the entire text is covered in one semester. Furthermore, the student is examined on each unit, so he effectively is examined on the entire book. The course is therefore much broader in scope than it is when taught in the conventional fashion, where often only eight to ten chapters of the text are covered. Of course the subject matter is not covered in as great a depth in the self-paced course, but the way is available for the student to selectively study topics in detail via outside reading.

The student tutors that were used ranged from sophomores to third-year graduate students. The tutor is probably the most important part of the course from the instructional side. The choice and training of the tutors is therefore an important part of the job for the faculty member in charge of the course.

Student Response

Most students liked the self-paced format of the materials science course, and have found it to be compatible with their existing study habits. However, about 15% of those students that enroll in the course find the demands of the "self-pacing" to be too rigorous, and therefore dropped the course. Less than five percent of the students actually recorded their dislike of the method of learning, independent of their inability to discipline themselves.

The grades of the students are higher in the course because of the imposed cut-off at 70%. Since one must always get at least a 70% on a given unit, averages must be above 70%. The average for the course runs rather high, about 3.3/4.0. This is not entirely justified by enhanced learning, and as such is a situation which must be remedied.

The failure rate of students in the course was about 5%. These were students who could not finish the course within the semester, and elected not to complete it early in the next semester.

Economics

It is difficult to assess accurately the cost of the course. The tutors were paid at a rate of $2.40/hour, and for a section with 70 students the total tutor cost was about $750 per semester. This cost is over and above the cost of the faculty member's time.

The first time through a course the faculty member spends roughly twice the time on a self-paced course than on a conventionally taught one. If the same notes and exams are used a second time through the course the load goes down to about that of a single section of 35 students taught in the normal fashion. Thus, on the second time through a self-paced course, a faculty member can teach twice the number of students in the self-paced mode that he can for equal work in the normal fashion. The added expense for the 70 student self-paced section of about $750/semester for tutors, is less than the cost of the faculty time saved.

It is important to note however that economic and time savings only can be justified for large sections. In Metallurgy Departments this usually means that only the service courses, like Materials Science, can be of economic savings to the department. If other courses are to be given in a self-paced mode they must be justified by the increase in student learning that occurs because of the self-paced method.

Deviations from the Keller Plan

The Keller Plan is based upon the theory of psychology that is termed behaviorism (for a very readable discussion on the basic beliefs of this system see References 6 and 7). If one does not accept this theory he probably will not be able to adopt all aspects of the Keller Plan. Such is the case with the author of this paper.

Two of the aspects that were not adopted in this course are the complete self pacing by the student and the one of "unit perfection."

As mentioned above, there were two "doomsdays" in the self-paced course presently being discussed. The first was at mid-semester, and the other was at the end of the term. Students were told that they must finish the eighth unit by mid-semester and the entire course by the end of the term. This was done because I simply do not accept the dictum that "the student is always right."[3] Sometimes the instructor must push certain students along to keep them at a reasonable pace. Human nature often contains that trait of procrastination. A little prodding from the instructor is needed in these cases. (Or should we say in the behaviorist jargon that the "positive reinforcement" for finishing the proper number of units by the specified date is that the student will not fail the course?)

The unit perfection aspect of the Keller Plan also was not used in this course. Seventy percent on an examination was enough to have the student proceed to the next unit. This was done because it was felt that a student who does "perfectly" on an exam the third or fourth time around does not have the same knowledge of the subject matter as the one who hands in a "perfect" paper on the first try. It appears to me that a perfect paper on the fourth try only reflects the ability of the student to know what will be asked. In fact some self-paced courses actually give the same examinations to students on their further attempts at "perfection."

Another reason that the unit perfection aspect was not employed is that it often places the tutors in the position of asking the student what he "really" means by a certain answer. Many students are able to talk their way into the correct answer, without being able to write it down during the exam. This tendency on the part of students to be imprecise in writing needs no outside encouragement, so in this course answers must stand as originally written. This makes it very difficult to obtain 100% in most of the materials science exams. (See for example question 3 on the exam in Appendix C.)

Summary

The self-paced materials science course developed at C-MU has been described and its distinctives have been delineated and explained. The course has been successful in teaching the "elements" of materials science to engineering students, and currently improvements on the course are being implemented.

Acknowledgments

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Finally, I would like to thank the tutors who worked with me on this course over the past two years.

References

1. F. S. Keller, "Goodbye, Teacher," J. of Applied Behavior Analysis, Vol. 1, (1965) p. 79.

2. J. G. Sherman, PSI Personalized System of Instruction, W. A. Benjamin, Inc. (1974), Menlo Park, California.

3. B. V. Koen, "The Keller Plan," Individualized Instruction in Engineering Education, L. P. Grayson and J. M. Biedenbach, Editors, ASEE (1974), p. 37.

4. M. M. Gore and J. P. Rayner, "Compact Cassette Tape Recorders in the Science Laboratory," Physics Education, Vol. 7 (1972), p. 215.

5. J. M. Biedenbach "Continuing Engineering Education Utilizing Video Tape," Engineering Education, Vol. 61, No. 8 (1971), p. 886.

6. B. F. Skinner, "Beyond Freedom and Dignity," A. A. Knopf, New York (1971).

7. B. F. Skinner, "About Behaviorism," A. A. Knopf, New York (1974).

APPENDIX A

A List of the Units in Self-paced Materials Science

		Chapter of Text*
I.	An Introduction to Some Materials Characteristics	Foreword, 1
II.	Chemical Bonding	2
III.	Ideal Atomic Arrangements	3
IV.	Real Structures	4
V.	Single Phase Metals	6
VI.	Electron Structure and Processes	5
VII.	Phase Relations	9-1 - 9-5
VIII.	The Iron Carbon System	9-6 - 9-9
IX.	Multiphase Materials	10
X.	Control of Microstructure	11-1 - 11-11
XI.	Polymers	7
XII.	Ceramics	8
XIII.	Corrosion of Metals	12
XIV.	Composite Materials	13

*Elements of Materials Science and Engineering, Van Vlack, Third Edition, Addison Wesley, (1975)

APPENDIX B

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UNIT VII - Phase Relations

Reading: Van Vlack, 9-1 - 9-5
Wulff et al., Vol. 1, 148-170

Up to now all the materials discussed have been composed of a single phase. When we talked about Cu or Fe crystals we really meant that the entire assembly of atoms were in identical surroundings, (neglecting, of course, atoms at grain boundaries or other defects). However, many important engineering materials are composed of more than one phase. The size, shape and amount of second phases greatly affect the properties of metals. In this unit, phase equilibria will be introduced to the student via the phase diagram. This diagram is of great practical importance. We will learn what information can be extracted from one, and how this can be applied to an understanding of the equilibrium properties of alloys.

It is important to clearly differentiate between a component and a phase. A pure metal (e.g., Cu) consists of one component (Cu) and one phase (fcc, usually designated α). However, Zn atoms may be substituted for Cu ones on some of the lattice sites. The system (alloy) then is composed of two components (Cu and Zn), but still only one phase (α, see Fig. 9-5.1). However, Zn atoms can not be added to the Cu lattice indefinitely. After a certain percentage of Zn is present, the system will be in equilibrium with 2 phases, α and β . (Fig. 9-5.1) (Note: α and β have different crystal structures and different compositions.)

The phase rule (not discussed in the text) is a simple relationship that tells us how many phases (P) may be in equilibrium together in a system containing C components, under certain thermodynamic restraints. It can be written as:

$$P = C + E - V$$

where E is the number of environmental factors
and V is the variance of the system (i.e., the number of degrees of freedom).

For most cases of interest to the materials engineer, E can be taken as 2 (temperature and pressure). As a matter of fact, since the pressure is often constant, E can be set equal to 1, and the phase rule becomes

$$P + V = C + 1$$

The number of degrees of freedom V (or variance) must be equal to zero or an integer less than or equal to C (assuming constant pressure).

For a pure system, $C=1$
and $P + V=2$

This means that if 2 phases are present in equilibrium (P = 2; e.g., liquid and solid) V = 0, hence there is no freedom of choice of the temperature. The temperature is of course just the melting temperature of the solid. If only one phase were present, V = 1, meaning the temperature may be varied by a finite amount without necessarily changing the phase.

It can be seen that a binary alloy (C = 2) can have a maximum of 3 phases in equilibrium at constant pressure and temperature, and 4 phases together only at a specific temperature and pressure (V = 0). It must be stressed that the phase rule and the phase diagram apply only to alloys in equilibrium. Thus, they may be used to tell what reactions will occur given enough time, but they can not be used to predict the kinetics of the reaction.

UNIT VII

Homework

VII - 1. A metal which is suspected of having more than one component solidifies at a constant temperature.
(a) Does this mean the metal is pure (i.e., one component)? Explain.
(b) What is the highest number of components allowed in an alloy which solidifies at a constant temperature?

VII - 2. A Ni-Cu alloy with 50% Cu is held at 1300°C until equilibrium is reached (see Fig. 9-2.2)
(a) What phases are present?
(b) How much of each phase is present?
(c) What is the Cu composition of each phase?

VII - 3. A Pb-Sn alloy of eutectic composition is held at 182° until equilibrium is reached (see Fig. 9-2.1),
(a) What phases are present?
(b) How much of each phase is present?
(c) What is the Sn composition of each phase?

APPENDIX C

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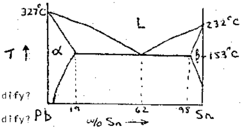
Date ____________ Name ____________

UNIT VII

Examination B

1. Alloys of Pb-Sn are often used as solders. The phase diagram is sketched (60%) below.



(a) At what temperature does a 62 w/o Sn alloy begin to melt? to solidify?

(b) At what temperature does a 40 w/o Sn alloy begin to melt? to solidify?

(c) How much α phase is there in equilibrium with β just below the eutectic temperature, for an alloy of overall composition of:
(1) 62 w/o Sn
(2) 40 w/o Sn
(3) 19 w/o Sn

2. Differentiate between:
(20%)
(a) mixtures and solutions
(b) Eutectics and eutectiods

3. Demonstrate the validity of the phase rule in the α phase region and the L + β phase region of the eutectic (20%) diagram shown in 1. Also show how it is valid at the eutectic temperature.