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Afterward

Instruction in materials science and engineering: modern technology and the new role of the teacher

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Abstract

Materials Science and Engineering (MSE) has been created by combining disciplines that are several thousands years old (Metallurgical Engineering) with quite recent ones (Solid State Physics). It includes atomic and molecular interactions and structures, synthetic chemistry, phase equilibria and phase diagrams, a variety of characterization methods, mechanical testing and fracture mechanics, visco-elasticity, rheology, materials processing from forging through sintering to injection molding, as well as prepreg making and composite manufacturing. Different sub-disciplines of MSE often require different instructional approaches. Teaching a single basic MSE course requires a combination of approaches. Fortunately, we have an increasing number of instructional tools: computer modeling (watching a known process); computer simulations (learning about an insufficiently understood process); interactive computer programs; TV broadcasting of lectures followed by discussions by phone, both video-recorded; the world wide web information accessible via search engines; the *Journal of Materials Education*; and traditional textbooks and class lecture notes. Moreover, MSE also exhibits certain unifying features (not limited to just, say, metals or semiconductors); these features are also discussed. The most important consequence of the existence of new technologies is the change in the role of the instructor. Instead of mostly dispensing knowledge, the instructor now has to make decisions. Particularly important in the new role of the teacher is his/her capability to make the student manage his/her time in a much more efficient way. © 2001 Published by Elsevier Science B.V.

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1. Scope

Successful teaching of Materials Science and Engineering (MSE) involves a number of requirements. Several of them will be discussed below:

- Recruitment of students.
- Sufficiently prepared students.
- Matching of teaching and learning strategies.
- The use of new technologies.
- Adaptation of the role of the instructor to the existence of new technologies. This aspect is very different from mastering those technologies. It involves, above all, providing the student with information such that the student can manage his/her time much better.

2. Recruitment of students and their preparation

To begin with, let me quote from an article by John Leo in 'U.S. News & World Report' [1]:

> Yet another big study shows that American students are well behind students of other industrialized nations in math and science. Among the 21 nations in the study, American high school seniors came in 16th in general science knowledge, 19th in general math skills, and last in physics. The U.S. performance was actually worse than it looked, because Asian nations,

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which do particularly well in these comparisons, were not involved in this study. Otherwise America might have been fighting for 39th or 40th place in a 41-nation field.

The International Council on Materials Education (ICME) has membership from Brazil to Ukraine, and we are able to make some comparisons. There is a reason why college studies in the US are so difficult. It seems that the freshman and sophomore years are often and necessarily devoted to teaching US college students things that in other countries their peers already know at the time of high-school graduation. Some courses that are truly at the college level are taught at the same time-making the student load heavier than it is abroad.

The college-level education, undergraduate and graduate, is thus hampered by inadequate literacy of incoming students. There are two reasons why graduate studies are included here. First, there are certain (fortunately not so many) post-secondary educational institutions that give their diplomas to people not sufficiently prepared for graduate studies, while those diplomas tell their recipients otherwise. Second, more frequent is the situation that the four-year college education might be insufficient for both catching up on deficient previous studies and acquiring university-level knowledge sufficient for starting post-graduate research. Thus, the issue of literacy affects all levels of education. The roots of the problem might be in an elementary or a high school where there is much money for athletics, while one of the coaches also teaches mathematics on the side.

As for specifically getting education in MSE, our discipline suffers from insufficient exposure at the high-school level. A high-school student who studies with pleasure Physics or Mathematics might be at least tempted to consider these disciplines for a career choice. The same student walking across a bridge might think about Civil Engineering for his college education. Materials are like air; they are everywhere around us, but they do not constitute a subject of high-school education and are mostly taken for granted otherwise. Therefore, we keep on encountering bright college students who tell us: 'If I had known as a high school senior that MSE exists, I would have chosen it as a career. Now it is too late.'

At this stage, the reader is probably thinking: 'These things I had some idea about, but is there a remedy?'. Actually, there is. I suggest that rudiments of MSE become the key component of Science courses taught at the pre-college level. Instead of teaching unwilling students abstract topics such as quantum chemistry including the Schrödinger equation, teaching MSE *instead* would convey to the students the idea that Science *is* related to everyday life! In fact, MSE determines the everyday life and the progress of humanity. This is not a self-serving declaration of us teachers and researchers in, MSE. Historians — and we have not bribed them — have concluded that the history of humanity is defined by the materials that people know how to use; thus the Stone Age, the Bronze Age, and so on. Incidentally, in case the reader now thinks that I am picking up on Erwin Schrödinger because as a student I struggled with his equation myself, let me inform you that I have *taught* a graduate course in Quantum Mechanics.

Needless to say, introduction of MSE into pre-college curricula is much easier said than done. It would involve the creation of textbooks by responsible scientists and engineers, while so many high school textbooks are a product of collectives of anonymous people, often with low competence, hiding behind others who lend their names for a profit. It is much easier to copy equations from earlier books than explain everyday phenomena. However, what is proposed here is doable.

A related issue is that of scientific literacy of the society as a whole. Modern technology is used by everybody, including those whose professions belong to the humanities as well as those who have never seen college. A specific initiative at the Portland State University (PSU) in Portland, Oregon, is worth mentioning. There is a course there accessible to all students who are non-science majors called 'Materials for the 21-st Century'. Not only is such a course taught, but its design and implementation have been analyzed by Kristi Miller of the Department of Mathematical Sciences of PSU [2]. One of the students commented afterwards that the course 'has helped me to look at things I may not understand and find information to help understanding it'.

3. Learning and teaching strategies

The following situation is typical. A teacher designs a course (not necessarily in MSE…) and teaches it successfully. A year later, say, the same instructor is teaching the same course, in a similar way, possibly with some improvements, but with poor results. The obvious conclusion of the teacher is: 'this time I had a class composed of much worse students'.

Given this typical situation, we cannot overstate the importance of findings of the British psychologist Gordon Pask [3–6] on teaching and learning strategies. He and his team concluded from extensive studies that people could be divided into two major categories of cognitive compentence: *holists* and *serialists*. Holists learn in a global way. When teaching them, one has to show them the overall panorama. Providing them with pieces of knowledge only will result in their losing interest in the course and getting lost. Serialists operate — and acquire knowledge — step by step. They are unwilling to make the next step unless they are sure that they have fully mastered the preceding step.

Teaching any class, one needs to take into account both types of strategies. Thus, teaching MSE, I begin with the overall panorama, which includes: the history of the discipline; its constituting parts and structure; the role of MSE for engineers, scientists, and also for laymen (that is for everybody); and the basic tools of the profession [7–9]. I fully realize that during that time, serialists think: 'these are some generalities, nothing worth writing down yet'. However, without these elements, the holists would be lost from the start. Subsequently, I begin to provide some 'specific' knowledge that would awaken the interest of the serialists. I am aware that at this second stage, the holists think: 'these are some details, I am not sure whether they are important, but fortunately I already know what the whole thing is about'.

It is now obvious why a given teaching strategy might succeed in one class and fail with the next class. Holists and serialists are not distributed evenly throughout the human species. A match between a 'pure' teaching strategy, be it serialist or holist, and the learning strategy of the majority can be achieved with a given class but not necessarily with the next class.

Needless to say, providing such a mixed teaching strategy, beginning with making holists happy, serves well not only in the MSE courses. However, MSE has been created by combining disciplines that are several thousand years old (Metallurgical Engineering) with quite recent disciplines (such as Solid State Physics). MSE includes atomic and molecular interactions and structures, synthetic chemistry, thermodynamics of phase equilibria and phase diagrams, a variety of characterization methods, mechanical testing and fracture mechanics, visco-elasticity, rheology, materials processing from forging through sintering to injection molding, as well as prepreg making and composite manufacturing. This list is far from complete! Given the heterogeneous nature of our discipline, assuring as much as possible the match between the strategies of the teacher and the known strategies of the learners is extraordinarily important here.

4. New technologies

Different sub-disciplines of MSE often require different instructional approaches. Teaching a single basic MSE course requires a combination of approaches. Fortunately, we have an increasing number of instructional tools: computer modeling (watching a known process); computer simulations (learning about an insufficiently understood process by re-creating its essential features on a computer); interactive computer programs; TV broadcasting of lectures followed by discussions by phone-both video-recorded; the world wide web information accessible via search engines; industrial plant and laboratory demonstrations; the *Journal of Materials Education*; and traditional textbooks and class lecture notes.

The distinction just made between computer modeling and computer simulations (introduced here for the first time…) might not necessarily be completely clear. Therefore, let me provide an example of each. We can create an animation of internal working of an injection-molding machine: from supplying the granules to the hopper via the molten polymer flow to the cooled final shape of the product in the mold. Such an animation will be useful for at least two reasons. First, looking at the injection molder, the student cannot see what happens inside; the animation provides complementary knowledge. Second, the animation is a piece of software that the student can run on *his/her own time* outside of the plant or the laboratory; for the importance of the student time management, see Section 5.

An example of computer simulations can be our own work using molecular dynamics. We create a material on a computer, be it a metal or a polymer, apply to it mechanical forces, and solve the equations of motion of the particles (metal atoms, polymer chain segments) [8,9]. Currently, we are investigating computer-created polymer liquid crystals (PLCs) [12]. Again, there is information gained that is not accessible experimentally. Looking at a PLC fracture surface under a scanning electron microscope, usually, we cannot tell where the crack started or how it propagated until fracture occurred. By contrast, in a molecular dynamics computer simulation, we can watch the formation and growth of the crack. The process can be related to the magnitude and directions of the applied mechanical forces, materials morphology and temperature. This can be further used for defining processing conditions and service performance of the polymeric material. We have an industrial application significance simultaneously with an instructional value. This is important also for the reason that the United States spends incomparably more money on research than it does on teaching innovation. This fact was noted by Rustum Roy in 1989 [13]. The situation has changed somewhat for the better since then, but by no means dramatically as it should. The situation in other countries is similar, with a few exceptions. When we cannot change the overall trend, creating something that serves both research and instruction is particularly worthwhile.

We are not going to discuss various technologies available now and in the future, although, for instance, new software usable in teaching MSE courses is reviewed periodically in the *Journal of Materials Education*. Much more important is the role of the teacher in the new technology environment. This issue will be discussed in Section 5.

5. New role of the instructor and the student time management

Before the appearance of the new technologies named in Section 4, the *information storage* capabilities of the instructor were the most important. The knowledge was flowing from the teacher to the students. Lecture notes were precious; together with the textbook, they constituted the main and often the only sources of information. Now, however, the world wide web, educational software, etc., are available. In the new technology environment, the student can get good grades without attending lectures at all. While this is not often done yet, it is possible.

This situation has fundamentally changed the role of the teacher. Instead of mostly dispensing knowledge, the instructor now has to make *decisions*. The observation that this should be so is not new. Already in 1971, Myron Tribus [14] pointed out that the teachers 'must learn to coach, not to lecture'.

Particularly important in the new role of the teacher is his/her capability to make the student to manage his/her time in a much more efficient way. Consider, therefore, the time management of the student. He/she manages an individual educational enterprise, usually without the information available to managers in industry. An industrialist knows what and how his/her competitors are doing. A student does not; grades of other students are secrets. Therefore, the student often does not know whether to increase the efforts in course X and spend less time on course Y, or the other way around. The pertinent information will arrive after the end of the semester or quarter in the form of grades, when it will be too late to do anything.

What the instructor can do — and by no means only in the MSE courses — is to provide weekly information on the standing of each student in the class with respect to the class average. Grading of homework assignments, laboratory reports, essays, presentations by students in the class, quizes and tests, etc., can all be used for that purpose. When we have done so, we have found that the student wants to know more than his/her own class standing at a given time. Input from the students was overwhelmingly positive on graphs that provide changes from the beginning of the semester. In other words, the student wants — and needs — to know not only his/her standing but also the trend: 'Am I going up or down with respect to my class?'.

We have argued above that the new technology allows the student increasingly to learn on his/her own time, using interactive software, for example. Thus, the technology also enables the teacher to provide the student information other than textbook knowledge, and at the same time enables the student to manage his/her study hours much more flexibly.

Most of what was said above applies to both undergraduate and graduate courses. Providing class standing of an individual might be excessive information, however, in small graduate classes. Under these circumstances, the students can infer their own standing from obvious information. The larger the class, and the less attention the teacher can provide to a single student, the more important to the student is the information on the status of his/her enterprise compared to the other learners.

6. Concluding remarks

At the end of Section 3, we have noted the heterogeneity of MSE, resulting in part from its history. Therefore, it is particularly important to point out in teaching common denominators whenever they exist. To give just one example, alloying of metals and blending polymers represent basically the same operation. Noting facts like this — particularly when metals and polymers are not 'neighbors' in the course program — is quite helpful to the student.

Necessarily, this paper covers only some aspects of the instruction in MSE. The question 'What courses should be taught in a good MSE curriculum?' has been answered by Russell Pinizzotto and James Marshall after a survey of MSE programs in the United States [15]. More information on the subject of this paper is available in the Annual Materials Education Workshops organized for the last 15 years by our Council and also occasionally in symposia of other organizations on MSE instruction (Materials Research Society, Society for Engineering Education; recently also Gordon Conferences on Materials Education). The ICME web site has the address listed at the beginning of this paper. As should be obvious, we recommend reading — and contributing to — the *Journal of Materials Education*. Paul Brown, Wendy Brown, James Clum and Mark Palmer are making important contributions to running that Journal.

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