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Learning Efficacy in Engineering: Translating the Results of Research on Teaching and Learning into Classroom Practice

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In this article, it is argued that, in order to enhance the learning efficacy of a class, the instructor and individual students need to work at it by establishing an inventory of teaching/learning skills and strategies, and improving them with practice. Mechanisms for doing so are discussed. The existence of a dynamic cycle of events that affects learning efficacy is proposed based upon the results of classroom experiments. Whether viewed from teaching or from learning, this cycle appears to consist of the same four elements, the relative strengths and weaknesses of which feed on each other to enhance or diminish learning efficacy, depending upon the circumstances. The four elements were identified as: prerequisite/subject Knowledge, Attitude, learning/teaching Skills, and study/delivery Habits (KASH). When strong elements predominated weak ones, it was found that the combination created a stable (KASH) cycle that enhanced learning efficacy. However, when it was the reverse that held true, the KASH cycle became and remained unstable, and the interplay among its elements then undermined learning efficacy, resulting in suboptimal performance, even leading to academic failure in some cases.

INTRODUCTION

Many practical problems arise in the classroom. In this paper, the author focuses on one of them: learning efficacy. Simply put, learning efficacy deals with how to optimise the learning that an individual student can achieve in a given class.

What is successful teaching and how does one achieve it? Similarly, what constitutes successful learning and how does one measure it? Does good teaching always lead to good learning? In other words, can an instructor succeed in teaching even when students do not learn well; and can students learn in spite of teaching that is inadequate? After all, while not a desirable outcome, the observation that *surgery was successful but the patient died anyway* is something that physicians have come to accept as a reality of medical practice.

Clearly, when it comes to teaching and learning, the instructor and the student have their respective responsibilities. But what are they conceptually and how do they relate to each other in a particular context?

For specificity, let us consider an instructor who has taught the same course for many years. For the sake of simplicity, let us suppose that, all along, this instructor has used the same textbook, the same teaching style, the same syllabus and the same assessment tools. It is very likely that this instructor will have made the following four observations:

- Specific topics in the course pose special challenges to all students year after year;
- In a given class, individual students experience different types of difficulties;
- When performance is used as its measure, the learning achieved by each class, as a whole, does not seem to remain constant year after year. Indeed, it can vary significantly with the group of students being taught;
- The extent to which different classes become engaged in the learning process also varies a lot.

If this instructor wishes to make progress in each of the four items listed above, what course(s) of action should this instructor take, and how and why?

In this article, the author outlines the experience the author has had in attempting to address these issues while teaching the following undergraduate courses for more than 25 years: statics, dynamics, strength of materials, fluid mechanics, thermodynamics, numerical methods and vibration analysis.

The rest of the paper is organised in the following manner: first, three key ideas are presented from the many that are found in the literature about learning. Next, teaching tips are summarised that have been gleaned from different references. These are followed by a presentation of lessons learned from the results of teaching experiments that the author has conducted over many years. Finally, the concept of the inventory of teaching/learning skills and strategies as a framework that can be used to analyse and improve learning efficacy in a given classroom is introduced.

TEACHING AND LEARNING IN THE LITERATURE

Why do some students learn better than others, even in the same class? Many theories have been advanced by psychologists on what learning is, how people learn and how intelligence manifests itself. Reasons that have been proposed vary. Some are based upon the concept of intelligence, while others are based upon teaching and learning styles; still others are based upon the nature of learning itself [1-5].

Different Kinds of Intelligence

Although the word *intelligence* is used frequently in society, there is neither agreement on exactly what it is, nor on how it manifests itself in the learning process. Indeed, the concept of multiple intelligence was introduced by Howard Gardner to help clarify this issue [4][6]. Gardner postulated that there are seven different ways through which people demonstrate intellectual ability.

Different Types of Learning

A review of 53 different theories of learning was conducted. It was facilitated by summaries made available at the Web site on psychology tips [5]. Some are based upon cognition, while others on the Stimulus-Response model of animal and human behaviour; still others are based on modelling the mind as a machine that processes information according to predetermined rules of action. These theories suggest that there are different ways of learning and that they require different types of instruction [7-13].

Teaching and Learning Styles

Experience shows that, given the same set of information, learners focus on different parts and types of it. Learning and teaching styles were introduced to capture and utilise the notion that there are different approaches to learning and teaching. As applied to engineering education, these concepts are ultimately related to the multiple intelligence put forward by Gardner, Jung's theory of psychological types, Yokomoto's attempts to apply psychological types to learning engineering, Godleski's efforts to determine intellectual compatibility between engineering students and faculty, and the work of Kolb, among others [14].

However, the common credit goes to Felder and Silverman, who established a popular model that consists of five dimensions of dichotomous learning styles [14]. These are preference tendencies that represent continua – not distinct categories. According to Felder and Silverman, each pair of dichotomous learning styles has a corresponding pair of dichotomous teaching styles associated with it.

Common Difficulties of Learning

The focus on learning and teaching styles can be misleading; however, because mismatches between them are not the only hurdles that learners encounter. Indeed, healthy students experience learning challenges and difficulties that have little to do with conventional notions of learning styles or disability. Keri reviewed and commented on the classification of learning difficulties proposed by Shulman [15]. Shulman arranged them in three different categories: amnesia, fantasia and inertia [16-18].

Amnesia is the chronic habit of forgetting what has been learned. Fantasia represents persistent misconceptions about what has been learned; here, learners believe that they understand something, when, in fact, their understanding is incorrect; unfortunately, the student is either not aware of it, or denies the awareness altogether. If one believes the constructivist hypothesis of learning, according to which new learning rests on the old, then, under fantasia, the edifice of learning is built upon a weak and precarious foundation. Under inertia, the learning that was presumed to have been acquired is inert. In other words, it consists of an agglomeration of things: concepts, facts, ideas, etc, with no demonstrable evidence of their abstract relevance or relatedness to each other, or their applicability to new situations. Keri added attitude towards learning to the list; not because it is a difficulty per se, but because it can be a source of it [15]. Experienced instructors know that dissatisfaction with, disinterest in, or apathy towards, learning a given set of material can have effects similar to those from amnesia, fantasia and inertia.

APPLYING THE RESULTS TO CLASSROOM PRACTICE

Each theory of learning (or cognition) comes with a set of assumptions of how learning occurs [5]. These, in turn, have implications on how one could organise materials for teaching and learning and how one could interpret the performance of instructors and learners alike. While there are similarities and commonalities among some of them, there is neither agreement on what learning is, nor on how to achieve it, although there are attempts underway in psychology to come up with a unified theory [19][20]. Even if one were to select one theory above all others, it is not always clear how instructors at different levels can use that theory to benefit teachers and students. Thus, there appears to be a gap between proposed theories and their implementation in practice; that is, between what is known and the extent to which the results are adopted for classroom practice.

An issue that is related to it is the paucity of evidence pertaining to the extent to which the various theories of learning have been tested in the learning environment in order to determine how well they conform to, or predict, how the mind works.

Thus, the beginner faces the following dilemma: on the one hand, while those (engineering) instructors who have been successful in helping students learn by whatever measure must have had ways of doing it; to this author's knowledge, they do not appear to have published widely the presumably well-articulated philosophical approaches on which their successful practices were based. On the other, while psychologists have articulated their ruminations on how the mind works, as well as how people learn best, and published them widely, again to this author's knowledge, they do not appear to have tested their proposals in the classroom, or at least, shared the results thereof extensively with the teaching community. How does a subject-matter expert, who has been appointed as a new instructor, structure teaching activities in a given classroom to utilise the results of research on learning or, at least, take advantage of the rudiments of successful practice that were gleaned from the experience of master teachers?

Results obtained from key publications that relate learning to classroom teaching are summarised below.

Enhancing Learning Efficacy Using Learning and Teaching Styles

Some observations that appear in the literature on the relation between learning and teaching styles have profound implications for classroom practice [21]. These are referred to as hypotheses, suggesting that they ought to be adopted by instructors and tested in the classroom.

Inherent-Bias Hypotheses

Each type of course, teaching style, delivery method, or assessment technique has inherent biases that favour certain learning styles and work against other styles. Felder illustrates this with the following examples:

- Teachers favour certain learning styles. *Teachers tend to favour their own learning styles, they instinctively teach the way they were taught in most college classes*;
- Traditional teaching formats favour certain learning styles. *The teaching style in most lecture courses tilts heavily toward the small percentage of college students who are at once intuitive, verbal, deductive, reflective and sequential … Sensing, visual, inductive, active, and global learners thus rarely get their educational needs met in science courses. Laboratory courses, being inherently sensory, visual, and active, could in principle compensate for a portion of the imbalance*;
- The choice and use of a particular teaching style do not have a neutral effect on learning. It affects some students positively and others negatively. Learning is enhanced when learning styles match teaching styles. *Students whose learning styles are compatible with the teaching style of a course instructor tend to retain information longer, apply it more effectively, and have more positive post-course attitudes toward the subject than do their counterparts who experience learning/teaching style mismatches.* This will be referred to as the resonance hypothesis: learning efficacy is enhanced when a learning style resonates with a teaching style;
- When students experience mismatches between the prevailing teaching style and their own learning styles, they feel as if the course was being taught in a language that they do not understand; both their grades and interest in the course material are likely to be low. In cases of severe mismatches, students may change majors or drop out. This will

be referred to as the casualties-of-teaching hypothesis. Thus, instructors need to ponder, if not attempt to reduce, the casualties of their teaching [21].

Enhancing Learning Efficacy Using Information on How People Learn

A review of research on how people learn was released by the National Research Council in 2000 [22]. It is rich in details and summarises the results of the new science of learning. Human beings approach learning having acquired some previous knowledge about the world. Thus, they have existing knowledge, beliefs and assumptions, and these affect what they consider, reject, retain or learn, and how. It follows that new information interacts with existing information somehow. Hence, there is value in knowing what the learner brings to the table of learning, as it were. In the literature on learning theories, this is known as constructivist theory of learning and it is associated with the name of Bruner [5]. A brief summary of the research on how people learn can be presented by using one major conclusion and three basic principles of learning [22]. Each principle is associated with recommendations and are detailed below.

Conclusion

There is no universal best teaching practice. The starting point is a set of learning principles that are followed by teaching strategies that are selected to help implement the principles.

Principle 1

Principle 1 is that a strong base in factual knowledge is essential to learning. Two important recommendations follow from this principle, namely:

- Teach the subject matter in-depth in order to provide a strong base of factual knowledge. And to strengthen understanding, use many different types of examples that illustrate the important concepts that are behind the factual knowledge to be acquired;
- Attempting to teach thinking skills without a strong foundation of factual knowledge does not work.

Principle 2

Principle 2 covers becoming familiar with the findings on how people learn and focusing on them in one's teaching enhances learning. Two important recommendations follow from this principle, namely:

- To the extent possible, determine what students already know (or think they know) about the subject and use such existing knowledge as a stepping stone to learning new material on the subject;
- Teach basics; connect thinking skills to them; use exercises that develop meaningful problem-solving skills; make clear the relevance and applications of what was learned.

Principle 3

Principle 3 relates to integrating the use of meta-cognitive skills in a variety of subjects or topics. Such integration improves learning.

LEARNING AND TEACHING IN THE SCIENCES

The relation between teaching and learning is easy to formulate in the abstract; it is hard to realise in practice. For example, engineers are dogmatic about the importance of competence. The unspoken assumption is that if you know it well, you can teach it well. Or, that if you know what to teach and know it really well, you should be able to figure out how to teach it well. In other words, competence in a subject matter equates to competence in teaching it. Therefore, the view of teaching as imparted knowledge seems endemic in engineering schools, despite the accumulating evidence that this concept is not necessarily valid; or, perhaps, more accurately, that it is mostly false. But in their defence, engineering faculty are quick to point out that no professional training in teaching is required before being recruited to teach at the university level in other fields either [23]. However, in reality, it is well documented that competence is necessary – but not sufficient – for good teaching and learning. Indeed, the relation between teaching and learning can be very elusive. Consider the following results of research in the sciences.

The physics community in the USA has invested considerable energy and time in understanding the relation between learning and teaching in that subject area [24-33]. The results of this research indicate that, in the sciences at least, the following four conclusions are true.

Firstly, competent and clear instruction does not necessarily lead to learning. Loverude states that:

> *Lucid explanations by the instructor and practice in solving standard homework problems are apparently insufficient to help students overcome the trouble they have*

> *with underlying concepts and lines of reasoning* [31][32].

Thus, as the old saying goes, *surgery can be successful even though the patient died*. This research suggests that one needs to understand what and how students think and to prove their understanding incorrect. Therefore, teaching efficacy involves helping students change their minds from incorrect ways of thinking to correct ways of thinking.

Secondly, passing a course is not necessarily synonymous with having understood the basic material of the course:

> *Ample evidence shows that many students successfully complete introductory physics without having developed an understanding of Newtonian dynamics. We found that difficulties with mechanical equilibrium were serious and widespread* [31][32].

Thirdly, the details used in teaching are important. *Whether instruction involves a tutorial, laboratory experiment, or some other mode, its effectiveness depends upon the details* [33]). By and large, successful instructional strategies are developed from experience in the classroom.

Fourthly, many teaching methods do not lead to meaningful learning. Novak has stated the following:

> *Much of the lack of understanding of biology can be directly tied to poor teaching and learning at all levels of our educational system. Our current system perpetuates rote, rather than meaningful learning. In effect, students are capable of sounding out the words in the sentences, but not of comprehending their meaning* [34][35].

LEARNING FROM THE CLASSROOM

Over many years, the author has studied the learning strategies used by two groups of students. The first group consisted of students who had been very successful not only in the classes taught by the author, but also in their undergraduate programmes. All of these students were at the top of their classes and, since graduating, they have gone on to be very successful engineers. The second group consisted of students who failed and dropped out of engineering. There appeared to be four key things, the understanding of which helped explain why the former succeeded while the latter failed. The author refers to them as the KASH principles; they relate, respectively, to *K*nowledge, *A*ttitude, *S*kills and *H*abits (KASH). These are summarised below.

Knowledge

Knowledge refers to comfort and competence in the use of prerequisite knowledge to which new information will be added. This is very important, as one would expect. What students know and do not know about the prerequisite subjects when they start a course will typically help, or hinder, their learning, respectively. Similarly for the instructor, competence in, and comfort with, the subject makes a big difference.

Attitude

Attitude concerns how students feel about, and the consequent predisposition of their mind towards, learning in general, the particular course itself, the subject matter of which the course is part, the instructor teaching the course and the institution they are attending; these either help or hinder learning. Their feelings do not have a neutral impact on learning. Similarly for the instructor, the attitude for the course, the particular group of students in it and the institution are very important, indeed.

Learning/Teaching Skills

Learning/teaching skills covers proficiency with the use of the necessary learning skills that will help them learn. However, when such proficiency is inadequate, performance suffers accordingly. Learning skills include, for example, listening, comprehension, reading and writing skills; the ability to follow the lecture while taking useful notes in class, to visualise operations of devices and machine parts as presented in the lecture material and problem statements, and to think and reason mathematically; and the proficient use of learning tools like tables of data and charts, electronic calculators and software to perform mathematical operations and produce graphics. Similarly for the instructor, proficiency in the various skills needed to teach course material is critical.

Study/Delivery Habits

Sound study/delivery habits include organisational skills, the ability to focus energy on a particular task without being sidetracked or distracted, the mental discipline to set priorities and follow through in order to complete assignments and meet prescribed deadlines, and the ability to recognise when they have come to the limit of what they can do and the willingness to seek assistance in a prompt manner. Similarly for the instructor, proficiency in the various skills needed to deliver course material is critical.

Discussion of These Four Aspects

There appears to be a cycle of behaviour that is rooted on these four aspects and it can enhance success or work against it. The author's classroom experience suggests that, when strengths predominate weaknesses, these elements combine to create a stable (KASH) cycle that enhances learning efficacy [36]. However, when it is the reverse that holds true, the KASH cycle becomes and remains unstable; the interplay among its elements undermines learning efficacy and results in suboptimal performance, if not failure.

One can start with one of the elements and connect the others to it successively. For example, it is as if:

- Good feelings enhance the production of the motivation to learn;
- A sound knowledge of prerequisites allows the learner to approach the task with self confidence or self efficacy;
- Good learning skills predispose the learner for success;
- Good study habits, in turn, allow students to persist or stick to the task at hand until it is completed successfully. Indeed, if they should encounter difficulties, students with positive KASH reserves are very likely to ask for assistance. In fact, it is precisely because they have good study habits that such students are likely to have started work early enough to have lead time that can be used to seek assistance when needed.

However, should the cycle be broken by serious inadequacies in one or more of these four KASH areas, the affected student is likely to be facing functional impairment and the cycle can become unstable very quickly. For example, in most engineering courses, new material to be learned and assimilated cumulates as the semester wears on. Consequently, small failures compound on others and the process sustains itself until, ultimately, larger failures begin to manifest themselves.

When the KASH potential becomes clearly incommensurate with the exigencies of the academic tasks facing the student, impending failures induce self doubts. When KASH reserves have become demonstrably inadequate, or have been exhausted altogether, some students become overwhelmed with work that they cannot do, while others become debilitated altogether.

CONCLUSIONS

An instructor who is interested in enhancing the learning efficacy of students needs to start by establishing a list of Teaching Skills and Strategies (TSS) that is appropriate for them. Each student similarly interested needs to determine an inventory of Learning Skills and Strategies (LSS) [36-41]. Table 1 identifies categories that must be included on this list.

The inventory shown in Table 1 is a mechanism through which an instructor and students alike may discover what they do in the classroom. It can be used to reflect on teaching and learning in order to know philosophically what one's personal beliefs, preferences and tendencies are. Felder and Silverman have a Web site that can be used to determine the learning styles of individuals [42].

After the inventory has been established and studied, the instructor can learn from colleagues and from what is available in the published literature on the aspects of learning that are of interest. The teacher can also establish the practice of using the classroom

Table 1: Inventory of teaching and learning skills and strategies (TSS and LSS).

Item No.	Teaching Skills and Strategies	Learning Skills and Strategies
1	Overall philosophy	Overall philosophy
2	How to deliver the material	How to learn the material delivered
3	The practice of materials taught	The practice materials to be learned
4	The assessment of what is learned	The assessment of what is learned
5	The assessment of learning difficulties encountered by students	The assessment of learning difficulties encountered by students
6	Positive proactive intervention	Positive proactive intervention
7	Self evaluation of performance	Self evaluation of performance

as a laboratory on learning for both students and the instructor. Such a practice makes it possible to test what other people have found to work and, in the process, discover what the specific causes of students' success and failure are, as well as the relationship among them within the relevant context. The existence of the KASH cycle proposed in this article was derived from the results of classroom experiments.

If institutional means, support and priorities allow the application of these ideas to the local context, an instructor has a framework for analysing teaching and enhancing the learning efficacy of students.

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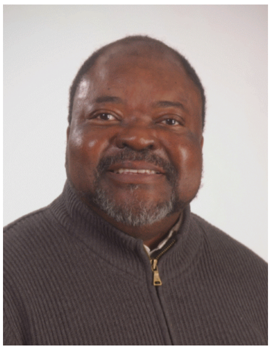
BIOGRAPHY



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