Astuta Ability Academy APS
Via Indipendenza 127/131
Civitanova Marche (MC)
Tel. *339 622 5234*
Segreteria. *segreteria@astutaabilityacademy.it*

"Education is what survives", W.Ernst Eder, Royal Military College of Canada

Nel 1964, in occasione di un'intervista, a Skinner viene posta una domanda. Gli viene chiesto di immaginare come sarà organizzata l'educazione e di conseguenza l'insegnamento 20 anni dopo.
Gli viene inoltre domandato che cos'è per lui l'educazione ("*What is education?).*
Skinner risponde dicendo che "l'Educazione è ciò che sopravvive quando ciò che è stato appreso, viene dimenticato" *(Education is what survives when what has been learned has been forgotten"* Skinner, 1964).
Quando il bambino va a scuola, le insegnanti tendono ad insegnare moltissimi contenuti relativi alle diverse materie. Questo avviene anche in parte perché la dimostrazione di tali conoscenze è un modo conveniente per misurare l'avvenuto apprendimento e insegnamento efficace. Ma c'è un altro aspetto dell'apprendimento che viene sotto stimato. Tutte le abilità che una persona mette in campo quando impara questi contenuti. Queste competenze come la capacità di apprendimento e le abilità specifiche che impariamo quando impariamo a studiare sono dei sottoprodotti dell'insegnamento di tali contenuti. Queste sono le competenze che Skinner definisce fondamentali. In altre parole, una volta che ci siamo dimenticati un fatto, un evento storico, una informazione (es, a quando risale la rivoluzione industriale?) cosa rimane dell'insegnamento? Ciò che rimane sono tutte le competenze che abbiamo imparato per poter imparare quei contenuti. Quindi la capacità di ricordare, di capire ciò che leggiamo, ecc. Per Skinner, 20 anni dopo, la scuola idealmente si concentrerà sull'insegnare queste competenze, ovvero il metodo di studio invece che contenuti specifici. Per Skinner questo è quello che sarebbe successo 20 anni dopo, cioè che questi sotto prodotti sarebbero diventati gli obiettivi principali della scuola. Ma nel 1984 (20 anni dopo) Skinner scrive "The shame of American Education" (la vergogna dell'educazione americana).
Da qui la nostra riflessione ci orienta sul come il nostro obiettivo debba essere quello di identificare le abilità di apprendimento di base, cioè quel repertorio che permette all'allievo di imparare nuove e successive risposte in modo più veloce.

EDUCATION IS WHAT SURVIVES -- DISCUSS

Conference Paper · June 2000

1 author:

Wolfgang Ernst Eder
Royal Military College of Canada

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W. Ernst Eder
Royal Military College of Canada

Abstract

"Education is what survives when what has been learned is forgotten." This quotation by B.F. Skinner contains several lessons for engineering education.

The teaching and learning processes in our educational institutions are supplements to the general learning experienced by student. Teaching and learning are intended to influence the levels of knowledge, the abilities and skills, and the attitudes and values of students. Each student builds, revises and maintains his/her own individualistic mental structures.

Knowledge can be divided into two groups, *object knowledge* and *(design) process knowledge*. Each of these has *elements* and *relationships*. Both object and (design) process knowledge should be explicitly presented in our teaching. Learning consists of adding to the facts and understanding -- and something will be un-learned. Both can be "forgotten," once the awareness and understanding about them exists in the student's mind. It is the understanding (of both object and process knowledge) that remains as tacit knowledge, and constitutes "education" in the sense implied by Skinner.

I. Introduction

B.F. Skinner once said: "Education is what survives when what has been learned is forgotten." Whatever are the current opinions about the methods advocated by this educational pioneer (e.g. operant conditioning), this quotation contains several lessons for engineering education for the new millennium (that starts in January 2001).

The teaching and learning processes that take place in our educational institutions are only supplements to the general learning experienced by each student. Students come into our institutions with extensive knowledge, abilities, skills, attitudes and values. Their most rapid learning took place up to the age of 5 years. We can only hope to influence their knowledge, abilities, skills, attitudes and values, preferably in a positive and useful way. And we are students for most of our lives. Nevertheless, a well-planned supplement of educational presentations is essential for most learners.

How far the knowledge, abilities, skills, attitudes and values of students are under the direct control of the teacher is doubtful. Each student will necessarily build, revise, maintain and (if needed) restructure his/her own mental structures (maps). These are in some respects different from those of any other student, although much will be culturally determined, i.e. held in common. If a new set is offered that students cannot fit into their existing mental structures, the new set may be rejected, or a difficult period of restructuring takes place. Learning thus consists of transferring the facts and understanding (as information) into the internalized mental maps, i.e. into the sub-conscious.

In addition, students can and do learn by themselves and from their peers. We, as teachers, should therefore make sure that our presentations are useful and in context, and that the students become aware of our opinions on usefulness. This especially requires that each course of instructions contains cross-references to other courses and their knowledge content, and to general life.

II. Characterizing Knowledge

Knowledge (and abilities and skills) can be divided into two groups (the boundaries are somewhat fuzzy):
-- *object knowledge* deals with facts, real phenomena (transformations, processes, operations, desirable and undesirable changes that we can influence), and real objects and their properties and behavior, as well as opinions, subjective assessments, heuristic "rules of thumb", etc.;
-- *process knowledge* deals with mental operations and procedures for accepting and processing information (e.g. about objects, including designing them), and includes formalized and informal methods, and internalized "tacit" knowledge.
Each of these has *elements* of knowledge, and *relationships* among those elements, usually at several hierarchical levels of abstraction and complexity.

In both cases (object and process knowledge), we can distinguish the *raw* facts and procedures from the mental images, *interpretations*, tacit knowledge, intuitions and models that we can summarize as *understanding*. Raw facts (as teaching topics) can easily be part of the vehicle for creating the understandings. For that purpose, the facts (object and process knowledge) must be coupled with the relationships among the knowledge elements. Both object and process knowledge should be explicitly presented in our teaching. But therefore a common theme must be found to tie all the disparate engineering courses together, throughout the whole of the educational experience. Such a common theme is provided by the Theory of Technical Systems[1], and Design Science[2], see[3]. In addition, a theory, appropriate methods, and the objects to which they apply should be coordinated and made explicit, i.e. taught and practiced[4,5].

If a person learns an organized procedure (whether physical or mental, or whether it is systematic, methodical, stereotype, or guided by prejudices), the procedure is gradually internalized into the subconscious (compare[6]) through the repetition and practice. Predominantly those parts of the procedure which are useful for the given (practiced) task are absorbed. Learning consists of adding to both the raw facts and the understandings -- and implies that something (conflicting or redundant, no longer needed or useful) will be un-learned in the process. The transmissible facts and the formalized methods have something in common. Both are to some extent expendable, they can more or less be forgotten. Once the awareness and understanding about them exists in the student's mind, the facts can always be looked up in the available external storages (e.g. literature). Process knowledge that has been learned well enough is transformed into tacit knowledge of methods, such that its origins and formalisms have been forgotten, it runs subconsciously. It is the understanding (of both object and process knowledge) that remains, and constitutes "education" in the sense implied by Skinner.

Müller has presented[7] three kinds of action modes. In *normal operation* (also called intuitive or second nature procedure), the activities and procedures run from the subconscious in the learned way, with low expense of mental energy, and this gives the impression of competence. If the problem presents difficulties, the person must depart from normal action, and work in a process needing higher expense of energy. In *risk operation*, the available experiences (and methods) are at times utilized together with partially rational processes (more formalized methods), in a not consciously planned trial (and error) behavior, which can occasionally be very effective. In *safety* or *rational operation* conscious planning occurs, with largely conscious processing of the plan, because the competence of processing the problem is in question. Still the person tends to utilize normal operation as much as possible, also within the other kinds of operation.

III. Teaching Goals

The goals for teaching should be elaborated in reasonable detail to guide this engineering teaching and learning of object and process knowledge. For instance, a comprehensive consideration of design process, product, theory, method and the human should take place during the whole of engineering education, throughout the (2, 3 or 4) years of the course, not just in specific design courses, and especially not just in capstone courses. Such factors can lead to competency, as defined in[8,9] . This competency has recognizable sub-groupings of:
-- heuristic or practice related competency -- ability to use previous experience (one's own, and that of others) as guidelines, including knowledge of useful limiting values as initial assumptions;
-- branch or subject related competency -- knowledge of a particular family of technical systems within which designing is expected, and typical examples of families of technical systems should be included in the curriculum (i.e. in addition to machine elements, and not just their engineering science theory);
-- methods related competency -- knowledge of and ability to use specific methods, under controlled conditions of following the methodical instructions, and eventually (usually after thoroughly learning the appropriate method) intuitively -- for diagnostics, analysis, experimentation, but especially for designing;
-- systems related competency -- ability to see analytically (reductionistically), and holistically beyond the immediate task, and to take into account the complex situation and its implications, e.g. as in the discipline of life-cycle engineering; and
-- personal and social competency -- including team work, trans-disciplinary cooperation, obtaining and using advice, managing subordinates, etc.
This is typically the challenge of providing a coherent engineering education, where each subject (course) is cross-referenced to the other subjects in the curriculum. Design Science[2], and especially the theory of technical systems[1] is one of the tools that can be used to achieve this coherence. A pedagogically sound theory of education should also be applied consistently (as a method) by all staff in a curriculum, but suitably adapted to the teaching/learning process as it exists.

An old Chinese piece of wisdom credited to Confucius says:

-- *Tell me and I will forget*
-- *Show me and I will remember*
-- *Involve me and I will understand*
-- *Take one step back and I will act.*

In the usual interpretation, the first two of this set of items are used to decry lectures and demonstrations, and to advocate only project-based learning. The last of these items is usually omitted, by itself it would even deny the usefulness of project-based learning.

People learn in different ways, verbally, symbolically and visually. They learn either for a short time (seconds to minutes), or for longer time spans. They learn best when doing something, especially with coordinated instruction, explanation, demonstration, mentoring and role modeling. Consequently, I would add:

-- *Do all four and I will become competent.*

But this implies:

-- Tell me in sufficiently small chunks (elements) that I can grasp, but do not neglect or obscure the context and big picture (relationships);

-- Show me clearly and visibly, both the phenomenon (including designing as a process), its structure, the underlying theory, and its context, not hiding the phenomenon behind high-tech measurement;

-- Involve me by letting me do the tasks under guidance, to give me sufficiently quick success and encouragement, not frustration;

-- And step back gradually, as I develop the insights of the big picture, and the abilities and skills to do the whole job.

This is especially true for designing.

IV. Thinking Operations

Some necessary or useful modes of operation in thinking (and acting, especially during designing) are:

--an *iterative* mode of operation, when a task is repeated (systematically, intuitively, or in a mixed way), each time with better understanding and knowledge about the circumstances and proposed solutions, and thus a preferred solution is approached;

--a *recursive* (decomposing) mode, if a task is decomposed into smaller parts, each part task treated by itself (but possibly under at least partial consideration of the other parts), and then the attempt is undertaken to combine the resulting part solutions;

--an *interactive* mode, if one or several thought chunks are captured and considered in sketches or other notes (e.g. on a computer screen) -- the interplay between short-term memory and the activity of generating the note or the picture impression help to expand the thoughts and add to completeness and precision;

--a *searching and selecting* (problem solving) mode, if for a task initially several solution principles are proposed and processed to a certain maturity, and only then a selection is made;

--an *abstracting and concretizing* mode, for although the objective is a concrete system, one must work occasionally in the direction of abstracting and on different levels of abstraction.

--a *sequential* mode, in which one (partial) problem is treated one step at a time, almost reductionist;

--a *simultaneous*, concurrent, parallel mode (usually only possible if performed in a team) in which several (partial) problems or steps are treated at the same time, holistically.

These modes of operation should not be regarded as separate. They can and should be utilized in continuous interplay, adapted to the problem. One can thus neither predict the exact path of the solution process in designing, nor the solution preferred by a certain examiner. Both can be guided to a certain extent through conscious application of suitable theories and methods.

The aim must be goal-directed *searching* for optimal *solutions* to a (design) problem[10]. At any suitable level of abstraction of a model of a technical system (engineering product), this search can be assisted by the use of appropriate (problem solving) methods[11]. The word "method" can be defined as a prescription for a procedure that can be used to help accomplish this search, either

explicit (in writing) or internalized (intuitive). According to the type of procedure, we distinguish two groups of methods:
-- A *discursive* method recommends a stepwise procedure that builds systematically towards a solution or set of solutions. Using discursive methods, a previously defined goal can be approached according to a plan. By different combinations of known elementary solutions, new relationships can be discovered, and therefore new solutions can be found. Such a method tends to be transparent and explainable, and the results are traceable to prior knowledge, even though the final results were probably not predictable. Even discursive methods can produce idiosyncratic results.
-- Solutions may also be found with the help of *intuitive* (problem solving) methods. These are methods that lead to finding new solutions by employing intuition (internalized prior knowledge), idiosyncrasy, opportunism and spontaneity. For the problem solver, approaches to solutions come suddenly into consciousness. Such a method tends to be non-transparent and unexplainable, bordering on the mystic, it depends critically on the personal experience of the problem-solver -- intuitive feel for design must be learned by long practice. A statement that someone "never uses any methods" implies that this person uses an intuitive method.
Both groups of methods can and should be used together, they complement each other. Such methods can be learned, and should be learned under relatively non-threatening conditions -- preferably in colleges, not during engineering employment where acceptance problems can arise[7,12,13,14]. Learning the useful methods to apply to a (design) problem must be done by a practical activity (with a suitable explanation, support, demonstration, mentoring), using the facts and understandings. In this way ("learning by doing") the necessary abilities are developed into skills and competencies. Once the method has been learned sufficiently well, the original prescriptive instructions can be forgotten -- they are already stored in the mental maps.

Neither a rigid systematic approach, nor a fully intuitive mode of working are adequate by themselves to make it likely that good engineering products result from the design processes. Methods or techniques for stimulating creativity or inventions (e.g. brainstorming, synectics, TRIZ, etc.) are also deficient, any ideas obtained from them still have to be verified for feasibility, and their embodiments in hardware/software still need to be designed to enable implementation.

Equally, neither approach alone can lead to effective learning of design. A judiciously chosen combination of systematic and methodical working and freedom of action, adapted to the problem, and performed by well-educated people using good tools in a suitable atmosphere is likely to increase the chances of getting good results.

V. Creativity

In order to be acknowledged and effective as *creative* in problem-solving, and consequently in designing, persons must show simultaneously the following components (i.e. you must have all of these before you *can* be creative):
-- an adequate knowledge of objects and principles, possessed or available to an individual or a group of problem solvers, including *tacit knowledge* contained in experiences, heuristics, intuitions and gut feelings that have not been explicitly expressed;
-- a knowledge of processes, especially a knowledge about design and problem-solving processes, both of which should be intuitively and/or consciously available to the problem solvers, and about different ways of modeling objects (products and processes) and interacting with those models;
-- adequate judgment, a sense of what is reasonable to expect under the circumstances;

-- an open-minded attitude, a willingness to accept ideas and suggestions (self-generated, or generated or brought in by others) and to associate them with other knowledge, but also a sense of care and attention for the subject to drive towards excellence, and willingness (and ability) to cooperate in a team;
-- sufficient motivation, including self-motivation (inspiration) and externally induced motivation (rewards) -- and influence of management;
-- ability to communicate (verbally, graphically and symbolically) to make the generated proposals visible, to present the proposals in useful forms;
-- level of stress, including effects of possible pressure of time or unsuitable management style and conditions;
-- recognition and *ownership* of the existence of a problem.
This composition of creativity, and the admitted variability among persons for each of these factors, probably account for the fact that psychological test instruments that try to measure a person's "creativity" and report one unitary result seem to be so inconclusive. Even with all of these, there is no guarantee that you *will* be creative, it depends on the circumstances. Creativity can usually only be *recognized* after the event, mainly on the novelty and usefulness of the results.

Creativity does not "just occur." Recent investigations in psychology have shown that creativity, generating novel ideas, occurs as a result of a natural tension between intellectual and intuitive mental modes[15] . The intellectual mode (systematic, methodical, structured, analytical) can recognize that a problem exists and can analyze its nature. In the intuitive mode (erratic, inconstant, non-calculable, playful) a sense of dissatisfaction can then arise, which triggers and motivates the mental interaction with the intellect to attempt to solve the problem. The oscillatory interplay between intuitive and systematic thinking modes and related procedures can result in creative proposals for solutions. Sufficient oscillatory *tension* must exist between the intellectual (scientific, methodical) and the intuitive (playful) mental modes for creativity to occur. Creativity (proposing novel solutions to a problem) has occurred as a result from using a systematic approach, as has been demonstrated, e.g. in[16]. The likelihood of obtaining a "best" solution can be increased, but not guaranteed, by systematic work.

VI. Summary

In summary, forgetting means that something (a fact, an understanding, etc.) cannot easily be recalled from memory, and/or something (a procedure and its method, etc.) can no longer easily be explained. Education is thus what survives when what has been learned is forgotten -- Skinner.

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W. ERNST EDER

Educated in England and Austria, with ten years of industrial experience, his academic appointments cover the University College of Swansea (1961-67), The University of Calgary (1968-77), Loughborough University of Technology (1977-81) and the Royal Military College of Canada, Kingston, Ontario. Ernst Eder has attained an international reputation in systematic design, theory, methodology and teaching.