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# Factors in the effectiveness in engineering education - conclusions from pedagogical experience

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ABSTRACT: This article outlines the author's contribution to the concept and transformation of the educational process. The bases of the experimental observations were classes in Building Construction conducted by the author in the Faculty of Architecture and the Faculty of Civil Engineering at Cracow University of Technology, Kraków, Poland. The most important measures concern *teaching subject cards* and *matrices of relations* between the elements of the teaching process, and teaching materials for students, with samples of instructive drawings. Other issues relate to the methods of primary learning, the problem of contradictions in the process of education and their reduction, the problems of proper balance between the model of *master classes* and the fragmentation of classes, and the damage to the process of education caused by the elimination of students' classes at construction sites.

Keywords: Academic teaching, engineering creativity, engineering education, teaching improvements, technical drawing

## INTRODUCTION

As an academic teacher, the author has been involved in the education of students since the beginning of his work at Cracow University of Technology, Kraków, Poland. Observations made during this period are an important part of the author's professional knowledge. The author would like to introduce his experiences into the education process more widely than just in discussions with other academics and students themselves. The goal is to make a contribution to the concept and transformation of the educational process. This transformation is not a short-term undertaking, but needs to be extended continuously. The main driving force of change in engineering education is the technological progress of civilization, so generally speaking, changes in the construction of buildings. Equally important (though not only in the education of engineering) is the generational change in the cohorts of students, to whom teaching is finally addressed. In the long term, this change includes multiculturalism, which represents relatively new challenge in Central Europe. In the author's view this is affecting the education process and, thus, the factors cannot be reduced to a purely technological denominator.

## RESEARCH BASE AND METHODOLOGICAL COMMENTS

The references at the end of this article are not a standard source of citations, but were intended to check if the article is original (it does not repeat contents already existing in the Web of Science). This research was conducted according to the keywords used by the author. In most cases, e.g. only rough similarities were found [1][2]. The widest range of issues about engineering education is available in comprehensive works by Nichols [3], Upcraft and Shuh [4], but the closest similarity of conclusions connects this paper probably with the article by Wu et al [5]. The similarities concern promoting of students' motivation and involving students in transformations of learning programmes. The experimental base comprises the author's observations made during classes conducted in the Faculty of Architecture and the Faculty of Civil Engineering at Cracow University of Technology, Kraków, Poland. These were mostly classes in technical and engineering subjects:

- *Building Constructions* within the specialisation of Architecture and Urban Planning, with all its transformations observed throughout the entire period of author's work at the Faculty of Architecture, which spans nearly 30 years. Hence, the author could make some observations of long-term trends, which could be briefly described as the transformations of fashion.

- *Building Constructions Systems* and *Building Surveying*, within the Erasmus students exchange programme - for a period of about ten years. These experiences form a broad spectrum, due to the enormous diversity among the group of students in the level of their knowledge, communication skills (which does not mean only the knowledge of the language) and, finally, cultural differences.

The author also conducted classes for a shorter duration of time (usually lasting a couple of years) in other subjects, among which the subjectively important were:

- *Building Constructions* within the specialisation of Landscape Architecture - representing a logical continuation of activities for Architecture and Urban Planning in the context of gardens, landscape and, generally, ecological aspects of architecture.
- *Structures for Building and Industrial Building* and *Exploitation and Modernisation of Buildings* - conducted in the English language at the Faculty of Civil Engineering.

NOTES ON *TEACHING SUBJECT CARDS*

Teachers conducting courses at the University are obliged to create *teaching subject cards*. These documents have a unified and regular form, and are prepared according to a single pattern. The goal is to organise the learning material prepared by different teachers and make a proper division into thematic blocks. However, there is also the distinction between the objectives/purposes of the education, and skills acquired by students. The necessity of describing the drawing skills as either a purpose or skill is more destructive than helpful in the teacher's work. It seems much more reasonable to create a list of issues, as much as possible parallel to the list of examination questions. The real challenge is to select and edit (theoretically countless) subtitles. Such an integrated document in its full version would also work as a supporting teaching material for students.

*MATRICES OF RELATIONS* BETWEEN ELEMENTS OF THE TEACHING PROCESS

Even more inconvenient are *matrices of relations* between the elements of the teaching process. Theoretically, they should explain the impact of one element on another, and create a sequence of implicative relations. The problem is that almost all relations are bilateral and their directions can be reversed. Even the most semantically distant paradigms may be adjacent to one another in one lecture (if not in one sentence), depending on the teacher's creativity in organising the materials. Let us consider the example of possible drawing skills as:

- Graphical presentation of the project (generally considered a basic skill of a general nature, substantially not related directly to any particular skill or expertise).
- Flat roof design including selection and sequence of layers (typically specialist knowledge, quickly outdating and closely related to available building technologies).

Both of them are desirable parts of the student's knowledge. At the same time, both are desirable skills. Knowledge and skills are obvious purposes of education. Moreover, these elements determine each other. Without the first there is *no way*, without the other there is *nothing* to show. Suggesting one way relations between them does not make any sense.

NOTES ON OUTLINES AND TEACHING MATERIALS FOR STUDENTS

While lecturing (in this case at the Faculty of Civil Engineering), the author came across a problem with materials for students. Troublesome was the requirement that the teaching materials always be passed to students *before* the current class. This was for two reasons:

- In many cases, it is essential to conduct a lecture by asking questions or proposing problems to solve in a manner analogous to the progress of technical knowledge, which (*historically*) took place. Therefore, it is nonsense to answer the questions before putting them up. This also causes a loss of attention from the audience.
- In the author's opinion, the best points or fragments of lectures are formed through the contact with an active audience. This cannot be obtained in advance, during the preparation of teaching materials. Is it possible to skip the obvious parts of the lecture? Or the opposite: is the discussion too brief? And most importantly, whether the new information is consistent with the students' existing knowledge?

*NAIVE* METHODS IN PRIMARY LEARNING

The illustrations in this article show some of the author's hand-made drawings used in primary learning in the first semester at the Faculty of Architecture. Of course, many of them are related to standard technologies in the central part of Europe, but now the purpose is to illustrate not the local technology, but the educational process.

The Constructions subject is relatively difficult for students in the first few semesters. One of possible reactions to such difficulties is irrational avoidance with the sophisticated knowledge, seen as an overcoming enemy. Figure 1 shows an attempt to present a technical problem in a *naive* manner. This may seem too easy for advanced students, but encourages the remaining section of the audience to *absorb* the teaching material.

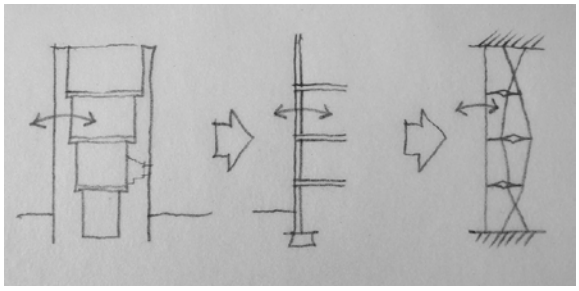

Figure 1: Sample of a hand-made drawing as a lecture illustration, simplifying a multifactor process to a set of symbols.

Figure 1 depicts the evolution of walls from historical massive structures to present day skin-glazing. The drawings show the problem of resistance to horizontal forces (see explanations in the article).

Figure 2 illustrates another aspect of encouraging the audience. The drawing is necessarily complicated, but its final shape is not important. However, the *relatively slow process of drawing*, enabling students to follow its emergence, and mental processing of only small pieces, one at a time, is important. Creating such drawings with proper explanations takes up to 45 minutes. In its final form the drawing includes the majority of issues sufficient for students to create their projects. At the same time, it shows the relationships between horizontal and vertical projections, supporting students' spatial imagination. This is also why the author encourages students to make sketches. The process of drawing helps in following and remembering the teaching material. Presenting the complete drawing at the beginning of the lecture gives the opposite effect.

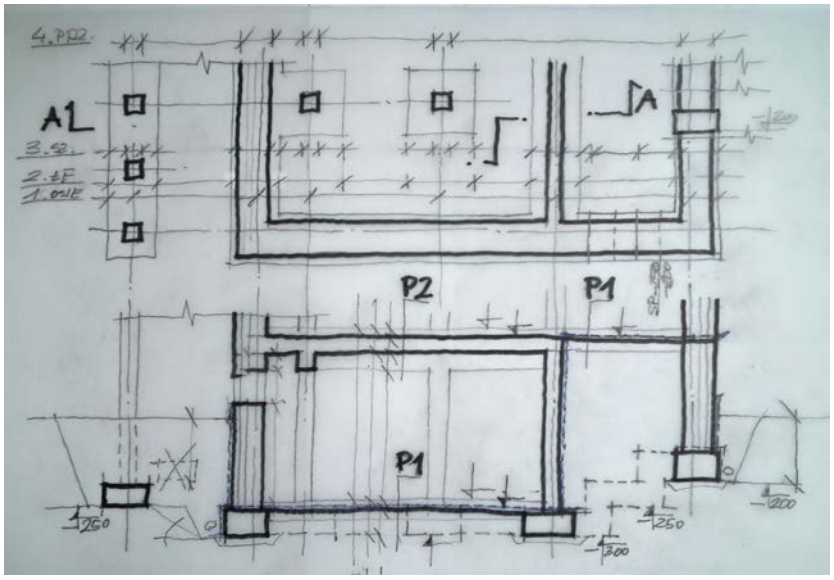


Figure 2: Foundation plan and section: 1) axes; 2) footings; 3) detailed measurements; and 4) relation to other drawings (basement plan). Important is not the final shape of drawing, but its slow emerging (see explanations in the article).

The part of a building shown in the illustration is not necessarily completely realistic. Such a set of elements would usually be present in several different buildings. The goal is to compress the knowledge into possibly few drawings, instead of presenting too many different pictures during the same amount of time. A similar idea is to group basic elements (below: of foundations in a single family house) within one drawing.

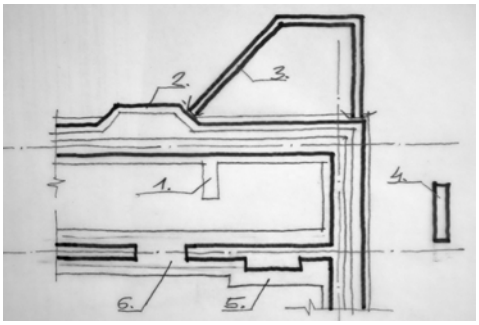


Figure 3: Foundations of a single-family house: 1) foundation for a concrete slab of a staircase; 2) foundation of a bay-window; 3) foundation for a terrace, structurally divided from a house; 4) support for an external staircase; 5) an extension of footing under a pillar; and 6) continuous footing under non-continuous structural wall.

Both sketches below serve to explain the relation between the geometrical shape of an arc and its static work. The algebraic calculation of forces is necessary to create a structural design, but not to understand the impact of the shape on acting forces. On the left, the theoretically weightless structure under the loading of identical parallel vectors finally forms a parabolic line. On the right, the loading is placed along the length of an arc (like links of a chain). The sum of acting vectors is always parallel to the axis of an arc. The method of considering static problems upside down (visible on both drawings, and historically assigned, *inter alia*, to Antonio Gaudi) is also useful as a way to create students' spatial imagination.

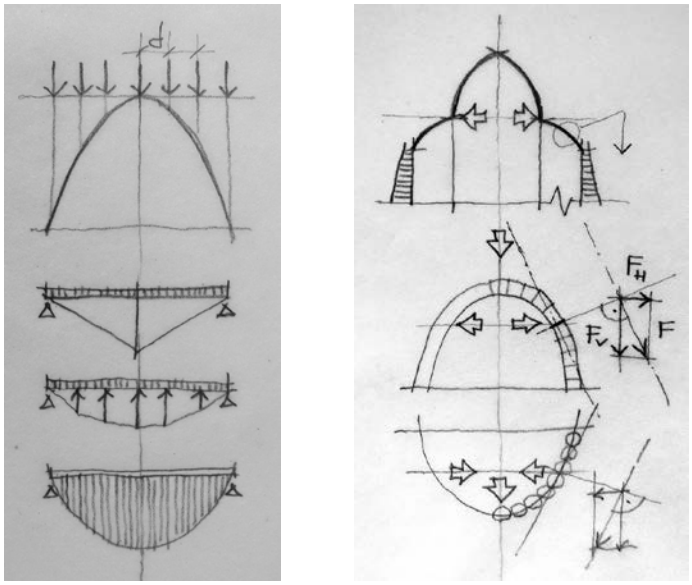


Figure 4: Rudiments of structures. Representation of mathematical relations by means of sketches. Left: a *parabolic curve*. Right: a *chain curve* (see explanations in the article).

*PROBLEM OF THE CORNER* AS A SAMPLE OF INTEDICIPLINARY TEACHING

Splitting the teaching materials into separate disciplines may give negative results, because some aspects of architecture have interdisciplinary character. In this case (see the illustration below), it includes knowledge presented in classes on construction, history, partially geometry and structures. As long as one focuses only on the problem of thermal bridges (on the left, class on construction), one does not realise that the building lost its modular rhythm. The *philosophical problem of the corner* (on the right) means that two modular façades create a *wrong*, non-modular intersection. Modular systems were mostly ancient Greeks' invention, but when analysing only the historical context, students can easily miss its relation to the 20th Century industrial technologies. In general, creating *cross links* between separate subjects makes the process of engineering education holistic and internally consistent.

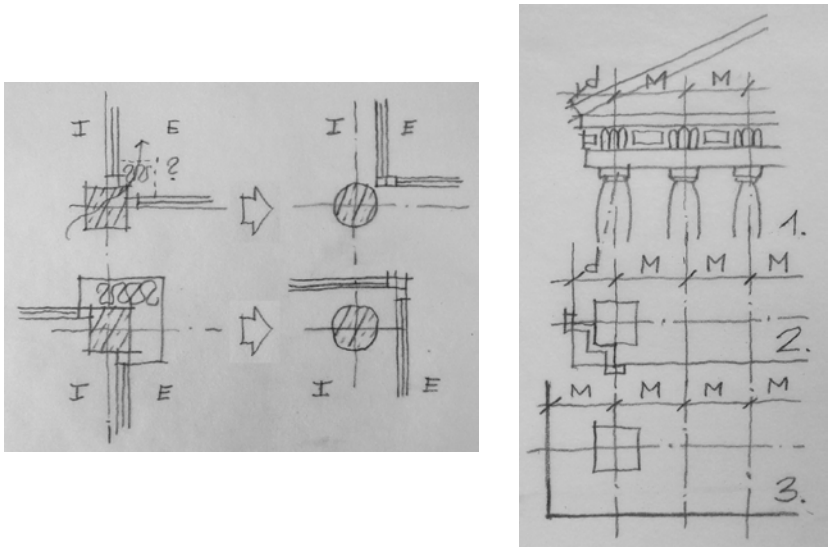


Figure 5: The *problem of the corner* has different meanings and, therefore, provides an opportunity to create interdisciplinary links between separate subjects. On the left: reduction of thermal bridge in the corner (I - interior, E - exterior) of a building. On the right, *philosophical aspects* of intersection of modular facades: 1) in ancient Greece; 2) in *contemporary classic* assigned to Mies van der Rohe; and 3) in other modular solutions.

## PROGRESS OF EDUCATION AS A REDUCTION OF CONTRADICTIONS

As long as simple issues at the school level are discussed, the existing knowledge appears to be completely consistent at the concept level for the student. But, this seemingly comfortable situation can end. Students encounter the problem of contradiction between the information coming from various sources. This takes place especially in the technical field. It is difficult to mention all the causes of this conflict, but the most important to the author are:

- The inevitable obsolescence of textbooks as a result of the ongoing technological development of civilisation.
- The classic dichotomy between professional and academic knowledge. The professional designer accepts (even ridiculous) rules and designs in accordance with them. However, students need something more: explanations and emphasising the advisability of the building law.
- Gaining by students the knowledge from commercial offers, depicting a false, idealised image of products and construction technologies.
- The availability of illegal or semi-legal sources of knowledge purchased by students, as an attempt to commit fraud in examinations. This knowledge, even accurately specified, gives a negative result. Students learn and mechanically repeat the *quick answers* and are not studying the real problems.

## *MASTER CLASSES* VERSUS FRAGMENTATION OF CLASSES

This issue needs introductory comments of a more general nature. By the term *master class*, the author means a group of students conducted by the same professor throughout all of their studies or at least for a couple of years. The author's favourite idea of teaching was to lead classes with the same students in several subjects. The obvious question is whether the teacher can be flexible and universal enough to lead classes in different subjects. However, one should consider that the knowledge of separate subjects finally sums up in the education of one and the same designer. That, as stated by Leonardo da Vinci, should only surpass the master.

In the author's opinion, master classes seem appropriate mostly in the world of art, where individualism is more important than teamwork. However, in engineering education, differences between groups of students in the scope and level of education are not so desirable. From the very existence of these differences, one can conclude that students relying on only one teacher are in some way handicapped.

At the other end of the scale is the atomisation of knowledge, and fragmentation and dividing classes into a huge number of separate subjects. This situation causes duplication of knowledge at the *borderlands*, and also creates a threat of internal conflict between different points of view presented separately by the teachers.

## GOLDEN MEAN: THE INTEGRATED DESIGN

Is a student taught by many teachers capable of developing a personal project and comprehensively correcting it? Theoretically, the idea of integrated design is to create the *golden mean* between the extremes mentioned above. But, its implementation also presents a few difficulties.

A student comes with his/her *philosophically ready* concept to another (technical) institute in order to translate the idea into the language of construction or at least to consult it. Then, he/she discovers that the abstract form he/she created, cannot be easily built in the real world. Therefore, the student creates a substitute, typically an unsatisfactory surrogate of the project, no longer returning to the original assessment. Thus, there is only a one-way relation instead of the synthesis of classes. That is why such an *integrated design* is not integrated enough.

## ELIMINATION OF STUDENTS' CLASSES AT CONSTRUCTION SITES

The most severe blow to the academic teaching by the increasing bureaucracy is the recent elimination of classes conducted on construction sites. It is a side effect of uncoordinated activities in the sphere of formal law relating to occupational health and safety (OHS). The training for academic staff at the Faculty of Architecture showed the negative change in the rules of conducting classes.

Officially, classes at construction sites are not prohibited, and the rules were only corrected in order to increase the level of safety for staff and students. As explained by the trainer *…It is only necessary to provide a statement by the construction manager, that he takes responsibility for the safety of persons on the construction site.* But, at that point, the negotiations come to an end. A construction company does not have any business in visits to the site by a group of students (especially, as big as 200 people). The most important bureaucratic mistake is that the insurance should work even if the class is conducted outside the University. The responsibility should never be borne only by the construction manager, but split proportionally by teachers and *students themselves.*

The problem is practically solved by teachers:

- By refusing to conduct any classes outside the University;

- By risking their careers and leading groups without official documents;
- By *private meetings* with students outside official hours (necessarily accidental, but surprisingly frequent).

The advantages of classes on construction sites can hardly be overestimated. Thanks to them, in the perception of students increases the correlation between the lines on the computer screen and the actual objects of architecture. What is more, both students and teachers can benefit from contact with the realisations emerging in the city, and practical (different from academic) design problems. The organisation of activities on building sites is logistically complicated. It requires an analysis of threats and a briefing for students on the site. However, the same training would be beneficial for the students as future engineers, working on the construction site for at least a period of professional practice. At this point, it is sufficient to say that the university teacher in consultation with the site manager is capable of leading classes in a safe and responsible way, as had been done for many years.

## CONCLUSIONS

Most of the conclusions were mentioned directly in the corresponding paragraphs of the article, so the summary below is partially one of repetition:

- A considerable proportion of bureaucratic *inventions* made at universities are more destructive than helpful for teachers.
- Explaining the algebraic function as a geometrical drawing can be quicker and less stressful for students, especially, in the rudimentary stage of education.
- Creating *cross links* between separate subjects makes the process of engineering education holistic and internally consistent.
- The idea of integrated design needs improvement by the means of bilateral communication between separate institutes.
- The lack of communication causes the risk of contradictions between teachers' opinions and programmes.
- The lack of classes on building sites is destructive to the process of future engineers' education.

## REFERENCES


1. Garcia-Garcia, M.J., Gonzales-Garcia, C., Fernandez, L.J., Casado-Sanchez, J.L. and Martinez Muneta, L., Assessing creativity in engineering students: a comparative between degrees and students in first and last year. *Inter. J. of Engng. Educ.*, 31, **1**(B), 343-353 (2015).
2. Gustina, C. and Sweet, R., Creatives teaching creativity. *Inter. J. of Art & Design Educ.*, 33, **1**, 46-54 (2014).
3. Nichols, J.O., A Practitioner's Handbook for Institutional Effectiveness and Student Outcomes Assessment Implementation. (3rd Edn) (1995).
4. Upcraft, M.L. and Shuh, J.H., *Assessment in Students Affairs: a Guide for Practitioners*. The Jossey-Bass Higher and Adult Education Series. Jossey-Bass Inc. Publishers (1996).
5. Wu, Y.W., Weng, K.H. and Young, L.M., A concept transformation learning model for architectural design learning process. *Eurasia J. of Mathematic Science and Technol. Educ.,* 12, **5**, 1189-1197 (2016).


## BIOGRAPHY

Robert A. Marcinkowski graduated a Master of Science and Doctor of Science in 1983 and 1996, respectively, at the Faculty of Architecture, Cracow University of Technology, Kraków, Poland. From 2002, he has also been a member of the Polish Writers' Association. His multi-disciplinary talents situate him in the worlds of science, art and culture. In addition to architectural design and teaching at the Faculty of Architecture, he deals with works in the fields of graphic design, visual arts, photography, music and poetry. He was commended at the Biennale of Architecture for a combination of poetic qualities in relation to architecture. In his pedagogical experience, he conducted lectures at different levels, from colleges to postgraduate studies. As an academic teacher, he has led classes and lectures of technical science, mostly in constructions, at the Faculty of Architecture and the Faculty of Civil Engineering. Since 2004, he has led classes in Building Construction Systems and Building Surveying within the Erasmus Programme. As a scientist, he has published articles representing a wide spectrum of knowledge, from typically technical, like traditional timber housing or solar energy in low-budget technologies, to humanistic, including ecological and sociological aspects of life. He has also lectured and published at the Faculty of Philosophy of Jagiellonian University in Kraków, Poland. As an architect, he has realised over one hundred buildings (at least to the state of finished construction), and many small-scale projects of interiors, gardens or partial renovations. He also creates theoretical and studio-based architectural projects not connected directly with the conducted classes. As a musician (guitar), he has recorded a CD album (2004) with his team, and takes part in several artistic events yearly (recently organised by the Cracow Council). As a writer, he has published individual books of poems, and has been included in collected works of poetic and prosaic creations. As a photographer, he has had individual art exhibitions (recently at the NCK Cultural Centre). He creates almost all the illustrative material for his scientific works himself.