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RESEARCH ARTICLE

A universal language in the engineering higher education role of descriptive geometry in laying foundations of engineering education

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Abstract

In past decades, the quantity of graphical data carriers and information transferred by them has multiplied. Selection, interpretation and reception of knowledge forwarded by images seriously try human visual thinking. In addition to traditional tools of engineering communication, computer-aided techniques are also spreading. These facts force us to reconsider the role and place of engineering representation in engineering education.

What values do this more than 300-year old basic subject represent in the university subject structure in the 21st century? What opportunities are there under which conditions for formation of visual thinking of engineers-to-be and their skills in drawing? This paper discusses these issues.

Keywords

descriptive geometry · visual thinking · engineering communication

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Engineering drawings are understood by craftsmen everywhere throughout the world. Unified symbols and way of representation unambiguously forward thoughts of designers without any language proficiency. The engineering degree certifies – among others – that the holder of degree knows the international language, symbol system and terminology of the given field.

A degree in higher education will only be granted to persons who have at least one language proficiency exam at medium level. Due to preferences in the entrance exam, a section of the students come to the university already with a language proficiency exam, however students have the opportunity to study foreign languages during the five years of their studies within curricula, from the level of beginners up to advanced level.

Training of the language of engineering communication begins at the University. At the beginning of their studies all engineering students face the fact that representation in drawings (either manually or by computer) is of utmost necessity in addition to verbal communication in all fields. Persons having passed an entrance exam in drawing are aware of this fact, but representation cannot be avoided at other faculties either.

“A picture is worth a thousand words,” a Chinese proverb says. The point here is not the difference in numbers but the fact that *a picture presents all information at the same time*, and understandably right away. Sorting and processing of information, preferences and interpretation of data depend only on background knowledge and attitude of the recipient. All this information could be *transferred verbally (in text)* rather lengthily, in the logical order of the author, *one after the other.* Therefore, graphical communication not accidentally comes to the fore (not only in engineering) [1].

Foundations of technical language are laid at the beginning of studies, most often as descriptive geometry or technical drawing within the curricula, with the primary objective to supply students with knowledge allowing them to understand professional subjects.

Professional subjects set manifold requirements:

- Knowledge of representing systems used in the given field (various axonometries, Monge’s dual planar projection, perspective projection and application of dimensions)

- Application of construction methods (plane transformation, rotation, sectioning, shadow construction, true dimensions)
- Realization of geometric interrelations
- Routine usage of various drawing tools (Indian ink pens, templates, French curves)
- Development of visual thinking
- Reconstruction from projections as a skill
- Correct representation of spatial tasks (thoughts)

The first four requirements can be met by correct subject matter and from the solution of drawing tasks. However, the skill of reading drawings (reconstruction from projections) and depiction of technical thoughts in drawings (skill of projection) do not depend on subject matter only, they are also rather time consuming. Geometric knowledge and spatial imagination of students are rather important here. Visual thinking of students is very different due to differences, their capabilities and in their studies up to university. That is why everybody learns "spatial imagination" individually, in spite of training in groups.

In the first 150 years of the Hungarian engineering training of about 220 years, this subject was taught with a high number of hours, some 12 to 16 hours a week and for 1 to 2 years, although, at that time science oriented secondary schools and technical secondary schools helped in laying it's foundations. Technological development, new materials and technologies to be taught have naturally led to a drastic cut of the number of hours devoted to basic subjects. Now, fundamental knowledge in representation necessary for studying professional subjects should be transferred even despite the fairly low number of hours.

Understanding of the subject material in the first lectures does not create any problems for students. Only after 2-3 weeks do the students realize that *most of them have no studying techniques for the new subject.* The receiving and understanding of new knowledge as well as its connection to former studies are more or less problem-free. The main concerns lie in representations in drawings. In an analogy to reading and writing , students are able to read at a certain level, however here, they learn how to form letters.

Subject matter can be dealt with in drawing tasks on different levels [2]. Students are able to apply knowledge delivered in lectures in similar situations or copy drawings seen in textbooks, however, if it comes to modification of a line in a specific position to a general one, or vice versa, it turns out that they learned only how to solve concrete situations rather than the construction method itself. (In educational units teaching this subject with a rather low number of hours or in a single semester, only constructions learned or studied are recited in exams. Here the lecturer's engineering background decides whether all routine constructions essential to engineering practice can be squeezed in the scarce time frames.)

The visual memory of architecture students is good enough at the beginning to grasp the subject matter as a view without understanding its geometric and descriptive contents. They try to compensate their lack in spatial imagination by their excellent memory [4].

Ways of geometric thinking of students coming from vocational secondary schools and grammar schools differ. Geometric knowledge hides behind excellent marks in mathematics and ranges from the minimum level up to mastery obtained in additional optional classes [5]. It is very difficult not only for lecturers but also for students to compensate differences in order to attain the level required and build new knowledge on it. (That is why not only students with poor spatial imagination but also ones developing slower or coming with the missing foundations repeat the semester.)

1 Acquiring knowledge visually or verbally?

Where are foundations of spatial imagination laid, *how does the spatial thinking develop*? This is a question that interested both psychologists and great physicists in the early 20^{th} century. Understanding of the theory of relativity – rejection of the independence of space and time from each other – caused a serious problem even for physicists [6]. On Einstein's advice, Piaget started to study the process of development of basic physical notions: space and time in the thinking of children.

Studying the formation of the idea of space brings us closer to the development of spatial thinking necessary in engineering.

In the formulation of H. Wallon (1879-1962), a specific level of spatial thinking is a requirement and a common basis for all kinds of intelligence. In the development of the idea of space (spatial thinking) *action* – attitude in a closed sense of the word – plays *the decisive role rather than perception*.

The formation and arrangement of movements and images in the mind depend on interrelations, the first model of which is space learned on the level of perceptions and movements. Experiments of Piaget (1896-1980) verify that our perceptions of space, i.e. our spatial thinking and *our ideas on space* are not congenital but are the *results of a long development process.*

3 to 4-year-old children do not distinguish between straight and curved lines, however, they already classify objects according to their topological properties. They know the terms of correct shape recognition, inclusion, order, nearness, continuity in practice. By the time they come to school, the ideas on uniformity and sameness are formed, the thinking of children attains the phase of concrete operations, they are able even to invert actions in thinking. They become aware of horizontal and vertical directions as elements of a reference system, as axes of a co-ordinate system by about 9 years old. The phase of formal operations is not directed to the concrete reality any more but on *reality as the function of the possible.* Space for opportunities opens up. Formation of notions like material, space, time, quantity is based on operational structures and recognition of invariances. By the age of 14-15 years the most sophisticated relations are formed, the development of thinking structures is concluded [7].

Piaget distinguishes four phases in the development of the thinking structure in terms of age:

- senso-motoric period (0-2 years),
- pre-operational thinking (2-7 years),
- phase of concrete operations (7-11 years),
- phase of formal operations (above 11 years).

Of course, social environment also affects the development process.

Psychological research has revealed that *verbal and visual thinking* coexist in our thinking and are in close interrelation. J. Hadamard (1865-1963) says that graphical and linguistic thinking drive each other, however, they both remain independent, moving quasi in parallel, this time the one, and then the other is driven to the forefront of the mind. Visual "concurrence" is – in contrast to the subsequence of language – one of the most important characteristics of our thinking.

In acquiring new knowledge, an *essential role is played by recollection.* Recollection is an active life process. Storage and recalling of information when necessary are important elements of thinking. New knowledge is processed and stored so that it is included into the existing structures.

Before the invention of printing, writing and reading were privileges of a small number of people; learning as well as the transfer of knowledge, its recording and transmission occurred orally, by manual technologies and in the form of drawings. Cave pictographs, pyramids, churches and their decorations are documents of mankind's knowledge on the world, they describe imaginary or real events preserved in time [8]. Ancient peoples processed information, first of all, in pictures, medieval visual thinking concentrated on complex symbols instead of notions and up to the 15th and 16th centuries, pictures and speech dominated the transfer of accumulated knowledge.

The general break-through of the Gutenberg Galaxy led to the change in human communication. Instead of graphical forms, verbal data conservation predominates with time. In the past 100 years, the quantity of books and contained information have increased to such a degree that written material of just one single professional field cannot be reviewed in its entirety.

J. Hadamard, the French mathematician interested in psychology, asked his coeval scientists about the nature of their thinking [9]. Answers reveal that a lot of natural scientists – chemists, physicists, nuclear physicists and mathematicians – understand a problem better if they "see" it, if the new knowledge is fixed in their *visual memories*. Scientific thinking makes use of the advantages of compacting the visual formulae of knowledge with linked operations and the interrelation of the visual and verbal memories promoting the thinking process.

The engineering memory is also of a visual type. Therefore engineering students with strong visual thinking are in a winning position.

Visual and verbal ways of knowledge acquisition together form our world concept. In different phases of life, stresses alternate, in place of natural visual thinking and sense perception, natural in childhood, comes verbal knowledge acquisition. Although in recent years, video and PC-based games positively influence visual thinking, imagination of real spatial relations, their representation in drawings is problematic even for this age group. However, all of us have the ability to operate visual channels from birth, but its developmental level depends highly on learning and practising. For students preparing for a technological career, the question "who can become an engineer?" is already decided in the primary school and not in the entrance exam. Practically, skills and abilities developed in primary education lay the foundations for the professional success of university students [9].

The information explosion has definitely led the teaching of drawing and supplementary subjects to decrease to a minimum. The level of ability required to represent spatial information in drawings is different for students, its development requires much more time. In nursery schools and in the first four classes of primary schools, playing with plasticine and with puppets, as well as drawing and reciting rhymes have the objective to link to and represent manual perception, visual and verbal experiences. Practising the description of landscapes, emotions and events in pictures and drawings, makes writing ultimately important in the development of visual thinking and communication [10].

The *training of visual memory* continues in upper classes in the form of text recall and processing sets of tabular information. During the mechanical learning of texts, linking texts to reality and feedback often gets lost. Secondary schools mainly develop verbal memory. Subjects predominate that can be taught and examined verbally more effectively and practically. Most pupils use their visual memories for formal "photography" of figures and texts (eidetic memory).

Secondary schools provide little opportunity and time for developing manual skills. The knowledge of pupils preparing for higher education is measured verbally in most cases; visual thinking is only tested in some institutions.

To start engineering studies, spatial visual thinking is necessary rather than knowledge of drawing techniques – students acquire these during training at the appropriate level. In most cases, the representation of thoughts in drawing and reading of drawings is problematic.

Engineering students have to acquire the same ability in reading drawings as in reading written texts. However, reading drawings is a more sophisticated task than the comprehension of texts. Drawings provide information not only concerning dimensions, material grades and arrangement but also on environmental connections (at the same time and not subsequently).

2 Knowledge of engineering communication tools

During the 200-year history of engineering education, knowledge of descriptive techniques of geometry and representation have been taught as basic subjects. Fundamental elements of *technical representation* are studied on the basis of *geometrical notions* learned in primary and secondary school. Subject material on representation systems and methods as well as their application develop constructive ways of thinking and the spatial imagination of students.

Before the 70s, this subject was highly ranked in basic training with a large number of hours. Training in computer science as well as a reduction of the obligatory number of hours for students have cut the time devoted to representational knowledge. It is true that institutions always stress the importance of this basic subject, yet, less and less time is provided for students to acquire fundamental knowledge. It does not matter that the number of hours of this subject (comprising drawing techniques and development of spatial imagination) taught in one single semester remains unchanged, a learning process of two semesters provides more opportunities for practising, more time for understanding and obtaining a mature knowledge. Knowledge of the language of technology is inevitable for every engineer. Unfortunately, the short time devoted to acquiring this language appears to show its drawbacks later during work. An object that cannot be imagined and drawn will not be designed. Geometrical properties of curves and surfaces that are not included in the university subject material should be collected, maybe explored through individual work. However, exploration, trial and measurement of behaviour or ways of application of these surfaces are challenges that not everybody can meet..

We dare say that students have a routine in studying languages. This should be utilized in the training of descriptive geometry. Words, idioms, basic notions should also be learnt in descriptive geometry, "rules of building sentences and of speaking" will be practised through geometric problems. This is the point where problems start. Due to the increase of the number of students, they work in classes not in groups of 5 to 7 persons, optimal for studying a language, and not in groups of 15 to 20 persons, still bearable, but in teams consisting of 25 or more. When studying a language, most of the background knowledge of students (family, weather, politics, and school) is homogeneous for the group, while *geometric basic knowledge of students is rather heterogeneous.* This should be levelled in a very short time.

The task of the lecturer in descriptive geometry consists, practically, in laying linguistic foundations. This means in the case of students with good spatial imagination, systematization of existing geometrical knowledge in parallel with studies in representation, but most students need to make up not only for missing knowledge but also their visual thinking should be developed and spatial imagination formed.

In the first steps of representation, the real appearance of the body or its model is an effective help. Observing the model presented, what is seen will be drawn - arranged as prescribed. This type of modelling, i.e. seeing and touching together *accelerates the formation of spatial imagination and internal visualization*. The model through its presence connects object representation in drawing and its reconstruction from the drawing, thus, making the learning process of drawing reading easier.

The development level of internal spatial imagination of first-year students determines essentially how fast and on what level they will be able to receive and process all knowledge in descriptive geometry, and to what extent they will be able to apply them in professional subjects. That is why in training descriptive geometry, unique attention should be devoted to the development of special awareness.

Students'ways of thinking should be modified so that they could again use *visual thinking* [12]. On receiving their degrees, architects should have this internal visualisation enabling them to imagine on the basis of the drawing not only the house in space, but also its relationship to the environment, options for its construction, the construction process and additionally, factors affecting costs [13]. Of course, professional elements will be acquired during university education. Recollection of structures of spatial thinking, natural as a small child and their development is of great importance at the beginning of the studies because various elements of professional knowledge will be integrated into this system. Early in the studies, training in descriptive geometry cannot rely on preliminary knowledge. For training spatial thinking, known material familiar to students should be selected, so they can concentrate on studying methods and techniques of representation. After representations of concrete figures – cubes, pyramids, prisms – in simple positions, their specific orientation in relation to planes of projection as well as their sections can be analysed. Having understood all this and practised it in their drawing, it becomes routine, object construction follows, i.e. the figure should be built up in space and constructed on the sheet knowing only some of the determining data (peaks and edges). With a continuous broadening of the range of surfaces, students can reach from representation on the basis of the palpable concrete model to representation of a general spatial structure in thinking and drawing. Through the solution of spatial geometric problems, spatial visual thinking can become excellently acquainted. At the same time it is a unique opportunity for practising on the same task all the three methods of world models, internally representing, coding and mapping the world: actions (enactive mode) by modelling; fixing images (iconic mode) by linking drawing and imagination; linguistic (symbolic) expression by explaining the correct construction stages and introducing their sequence maybe through description.

During the solutions of spatial geometric tasks, the *strategies for the solution to new problems* can also be developed in students' thinking. Every task begins with understanding the problem. Then existing conditions should be synchronized with the experience and the knowledge obtained up to that time, the spatial solution should then be constructed, and translated into the drawing language of construction and representation. Finally, a number of possible solutions and correct construction will be checked. Practising occurs in the world of geometric shapes familiar for years. Curved surfaces will be dealt with after sections, transparency problems and shadow construction of simple rectangular bodies. Every child has a ball as one of the most important toys. Yet, when studying sphere's planar sections, the imagination of relevant spatial circumstances is problematic. The second semester is not accidentally devoted to practising acquired knowledge in different situations rather than learning new representation techniques. Construction of curved surfaces' views, sections, contours and shadow has as its objective that students will realize that always the same constructional operations are carried out, only the shape of the surface changes. Now, the final step that remains is to replace the geometric surface with a building. Although this seems to be a rather small step, some time is required for finding sections necessary in addition to the drawings of the ground-plan and façade as well as for becoming able to "see" them. *Structures known from geometry will slowly be filled with professional content.* To see simple geometric shapes is much easier than a house or a staircase. Model making helps this process. Just as in the first year, students obtain from departments tasks in spatial arrangement and to model buildings to scale in parallel to studies in descriptive geometry. When making the model, students become aware of relative dimensions and orientation of the individual units, the shape of the building, its spatial position and relationship to the environment. Furthermore, students not only in thought but in reality deal with compilation, "construction" order, the stability of the model and with static relationships.

Within design subjects, visual thinking will be consequently deepened as for all semester design tasks also the model should be prepared. This means not only the realization of the shape corresponding to the plan drawn but also statical, structural and aesthetic checks. Students in the upper years consider a serious proof of their spatial imagination skills to draw the section of a building. This is the detail that is present in reality, however can never be seen. This is the real measure of correct and developed spatial thinking. Students in the second year still draw stairs in their plans that cannot be climbed. Images of the stairs and images of the buildings exist in their minds and in the drawing separately.

What image does exist in the students' mind? Is their spatial thinking correct? Does the drawing mirror the spatial experience developed in the mind, or is the drawing merely a logically arranged collection of representation conventions learned without forming a building from shapes? All these are questions on which we do not really know the answers. There is no measurement tool indicating how much of their drawings the student sees or vice versa, or how much of what they see in their imaginations they are able to represent.

It is not sure that descriptive geometry is taught at the optimum age at the beginning of higher education studies. Development of spatial awareness of students is already concluded at the end of the primary school [14]. However, students preparing for a technical career have a better spatial thinking than the average by birth or due to environmental influences. Therefore, the study time (2 to 3 years) necessary at the optimum age can be shortened. The experience shows that at least one year of foundation is necessary for meeting reconstruction and representation requirements of the professional subjects properly. Otherwise, students seem to be unfit for the career chosen and attain their goals with great difficulties only. However, most of them perform poorly because they have fundamental deficiencies in drawing communication.

After fundamental representation knowledge, students are studying the professional conventional representation language for years, but specialized subjects do not concentrate on training in representation. Due to an explosive increase in student numbers and a decrease in teachers, practically, knowledge acquired will be assessed in all years in writing only, mostly in the form of drawings. Here, deficiencies in knowledge of the given subject and in drawing presentation cannot be clearly distinguished. This is a reason why only a small number of students are able to obtain their degrees over the five years. Drawing communication is inevitable in all fields of engineering as people working in management or construction can do a perfect job only with a precise knowledge of plan details, also explanation sketches at building sites are often required.

The decisive role in representation of internal images in drawing and in development of drawing skills and techniques is played by training in drawing and composition during almost all of the studies.

For engineering communication the ability to read drawings and drawing plans is of fundamental importance. Reading drawings is acquired by all students by the end of the 5th or 6th semester as a routine. Their skills in representation of plans in drawings are developed during complex design and during preparation of the dissertation work. Modelling is an inevitable tool which also builds a good professional design ability. The model is an obligatory enclosure both of semester plans, complex plans and dissertation work. In professional design competitions computer-aided graphics and animation also appear. Development of computer-aided representation, applied in the last 15 years also in university education, presents a new opportunity for modelling. However, computers do not provide help in the education of descriptive geometry, as figure representation requires different background information than from drawings.

Application of some design and construction programs rely on internal spatial thinking of the designer through which phased drawings necessary for representing the building will be loaded into the computer memory from the "memory" of the designer [15]. In reality, this requires from students *one more level of abstraction and knowledge* than traditional drawing. In addition to representation methods in drawings, the construction problem should be translated into the *communication* language of the *machine*. (In most cases, computer drawing instructions do not follow the steps of traditional geometric constructions; shapes to be represented should or can be defined in a different way.) Although computer-aided architectural design programs spare us a lot of tiresome manual work, selection of the right dimensions, distances and view or position of the individual structural units cannot occur without a solid spatial perspective. The internal view formed and a reliable geometric base significantly reduce the time needed for computer construction.

At the same time, computer models provide the opportunity to model the spatial experience of the designer. With the help of the computer we can visit the rooms of the planned building, and latent errors of the building or the drawing can be detected [16].

Modelling as a tool of engineering communication accompanies students during their studies, forming their abilities to receive and select visual information and to represent new information. Design tasks of various subjects provide the opportunity to learn and practise usual representation methods, the standards and terms of the given field. However, they do not compensate for deficiencies of a foundation or developments of spatial thinking – and neither is this their objective.

Teaching and learning the engineering language is continuously present througout the whole of education, however, not detectably in the curriculum. Teachers of descriptive geometry or engineering representation in the first year only begin a process with the students verifying the acquisition of the professional language in their dissertation works.

University education prepares students for understanding a plan drawn anywhere in the world and for appearing with their thoughts and imaginations in the form of plans in the "world market".

In the past years a growing number of students take part in education or practice abroad. Their studies are facilitated by the fact that in addition to the language of the receiving country, the language of professional communication is also used. These trips and international design competitions are excellent for students allowing them to compare their knowledge with those of other countries.

Methodology and tools for studying foreign languages have considerably increased in the last two decades. Students can chose from subject materials of different types and mirroring different approaches. In addition to textbooks and workbooks, audio materials and self-learning cassettes as well as CDs are the results of methodological research and innovation, contributing to effective learning. The importance of foundations in engineering language in higher education is less obvious, the support system of studies is incomplete, there are few textbooks in Hungarian and their approach differs with institutions. None are really fit for self-study. Textbooks or lecture notes mirroring the reduction in number of hours are not available yet. Training aids and textbooks can *only help* self-studies, allowing practice at home. However, some of the tasks should be introduced during classes so that students could understand and follow constructions included in the book. Practically, it does not matter whether it occurs at the blackboard with rulers and compasses or with a projector. Architecture students may turn for help in studies to their teachers, to other students or architects only because beyond them there are few who are able to consult the subject material.

Palpable *visual aids* could be of great help in studying this subject. Rather few models have been prepared in the past fifty years. Early in the 20^{th} century, high-level models of geometric surfaces came from French and German workshops. (The richest collection of them is in possession of the Budapest University of Technology and Economics.) Green-red figures in the appendix of some descriptive geometry textbooks provide a real experience of spatial visualization. They contain geometric surfaces represented by their characteristic lines and sections. These pictures are excellent for representing abstract geometric notions in space [17]. Realization of both printed and manual models is rather costly, and their effectiveness and return cannot be measured directly. For surfaces discussed in the second semester, often students prepare models.

Despite the more difficult circumstances many students obtain a degree in engineering. In the results attained, the motivation of students plays a role of the utmost importance. If a student graduates from any higher educational engineering institution, their degree certifies that they have acquired the full toolkit of verbal and visual communication used in the given field.

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