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Technical Drawing in Engineering Education: Tool for Engineers' Communication, Design and Ability Development

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Abstract: *Technical drawing is a core of many engineering and design courses. The goals of this research are to assess whether engineering students who studied technical drawing at the university, using traditional tools for drawing and computer tools, improve their intellectual abilities, especially the effectiveness of perceptive and cognitive processors. The pilot research consists of two studies: (1) a correlation study of students' abilities and pre-university experience with technical drawing courses; and (2) a quasi-experimental study of the effects of technical drawing courses on students' abilities. The sample consists of 46 first-year undergraduate students in engineering departments (study 1) and 12 students selected from the first group after completing the course and passing an exam. The correlations between students' ability to visualize spatial relationships and achievement in presenting a three-dimensional model in three projections are confirmed. The second study confirmed that the students' perceptual processing abilities improved during the technical drawing course. In conclusion, the importance of learning technical drawing for some abilities development is emphasized, some research topics are opened, and some educational implications are suggested.*

Keywords: *Technical drawing; Mechanical engineers' abilities development; Perceptual abilities; Spatial abilities; Engineers' education.*

1. INTRODUCTION

The technical drawing or engineering drawing is an effective way of engineers' communication, cooperation and collaboration, conceptualization and coordination. It is an essential tool for communicating ideas and concepts in engineering and industrial production, for understanding the design process, and transformation an idea into the product (real thing). Technical drawing is an international language, a professional language without borders. The standards of technical drawing, as an international convention (standardized principles, signals and symbols) enable a uniform application in a wide range of engineering.

Technical drawing is a step that mechanical engineers absolutely have to master in order to present their product in the developmental and design phase. Therefore, technical drawing courses are necessary for engineering students for their professional education and career development, as well as for effective professional communication.

Technical drawing is a major part of engineering university education. As a *method of communication* by graphic means, technical drawing is widely used in different professions (engineers, designers, architects, graphic designers, photographers, artists, cartographers, chess players, video-game designers) to transfer information about various objects (machinery, products, structures, buildings, traffic), or to share technical information [1]. The other very important functions of technical drawing are the *visualization of the idea and the design and construction of the objects*. Visualization as a process of engineers' creative activities and as a universal visual language enables the transfer of ideas and information about the approach to construct something, or specificities of functioning between engineers in different cultures.

Technical drawing is a core part of many design courses. Although teachers and engineers use two terms – technical drawing (TD) and engineering drawing (ED), the basic concepts and standard conventions and rules for TD and ED are common [2]. The visual and spatial intellectual abilities and skills are the basis for TD/ED as a form of graphical communication. The conception of teaching and learning skills of technical or engineering drawing is the same.

Recognizing that visualization of the problem is a very important tool required in the technology and engineering professions, researchers [3] emphasized that visualization of problems has a formative impact on the success of technical /engineering education and will be used as a predictor of success in several engineering and technology disciplines [1, 2, 3, 4, 5]. These abilities are necessary for technical problem-solving success.

On the other hand, the researchers confirmed that TD courses affected spatial ability [6, 7, 8]. Results indicated that the TD course caused a significant increase from the pre-test to the posttest, with a significant positive relationship between spatial visualization abilities and spatial orientation abilities [2]. In the experimental research of the impact of engineering three-dimensional modelling (3D modelling) with SketchUp computer programme on the development of students' spatial thinking and visualization, in the context of previous experience with 3D modelling and students' achievement in the course Technics and Technology (secondary level of edu-cation), the researcher confirmed "that introducing spatial modelling with SketchUp in early technics and technology education enables more effective development and improvement of children's spatial visualization ability skills" [8]. Review of research on spatial ability improvement in the context of TD teaching emphasized that "several researchers have suggested that spatial ability can be enhanced and taught by some instructional designs" [3]. Drawing and spatial abilities share mutual training [9].

This paper investigates the mutual connections and formative impact between abilities, achievement in technical drawing courses at the university educational level, and educational settings.

1.1. Technical drawing and intellectual abilities and skills

Abilities are important and formative for academic and professional achievement, and some educational activities are formative for ability development. Researchers confirmed that it is possible to improve skills and abilities through educational activities [2, 4, 10, 11, 12, 13]. In the field of technical and engineering education, as a field of visuo-spatial engagement, spatial ability, and perception skills are very important and formative factors of efficiency.

According to Gardner [14], spatial intelligence, or spatial-visual intelligence, is the ability to think abstractly and in multiple dimensions. Based on spatial reasoning and conceptualization, it means keeping their cognitive maps in multiple directions and dimensions in their head. Humans with higher spatial-visual intelligence are thought to have a heightened awareness of individual physical spaces or environments. Some occupations of humans with higher spatial intelligence may include architects, mechanical engineers, artists, video-game designers, etc. [14, 15]. It is manifested as "the performance on tasks that require: the mental rotation of objects, the ability to understand how objects appear at different angles, and how objects relate to each other in space" [1]. Spatial ability is the mental manipulation of objects and their parts in 2D and 3D space, consisting of two major components: spatial relations and spatial visualization [16].

In the review of the research and literature about the importance of the spatial ability to vocations and other cognitive areas or academic disciplines, some conclusions are the following [2]:

- There is an association between spatial ability and performance or interactions and success in technical drawing and several occupations that require spatial understanding.
- The spatial ability could be increased with training, instruction, and practice.
- Spatial skills increase with vocational subjects.

Researchers identified some factors of TD effectiveness as spatial visualization, spatial relations, spatial orientation, spatial cognition, spatial intelligence, spatial ability, and visualization [3].

Spatial skills "promote a holistic understanding of engineering graphic tools, techniques, and processes" [4]. The spatial ability of two groups of engineering students is compared: the students studying TD at the pre-university and university levels and the students of philology not oriented towards engineering. The main results are showing that first-year engineering students present better visual discrimination and spatial memory than philology students. Therefore, improvement of spatial skills is possible through science, mathematics, and drawing classes [4]. Measuring spatial skills of the students before and after spatial ability enhancing courses, with three tests (mental rotation, mental cutting, and spatial visualization test), the researchers show similar results with the prior research [4], that the students' performance in the post-test measurement was improved, but differently in various sample groups and test types: first-year students improved significantly, but only on two of the three used tests [17].

The research on the participant's performance on a range of spatial cognition tasks considered important to designers, two groups of university students are compared [1]: a skilled group and an unskilled group, based on whether or not they had prior TD experience. The skilled group did consistently better on spatial ability tasks, with differences in performance shown to be statistically significant. Those tasks requiring advanced spatial skills associated with coordinate systems were found to be difficult. Other tasks requiring spatial reasoning to identify 3D properties from 2D produced better results than expected.

Based on a review of the results of other studies that showed "spatial ability can be improved through direct training with tasks similar to those integrated into the tests used to measure the ability," the experimental research with the aim "to analyze whether the indirect training in Technical drawing improved the spatial visualization ability of architecture students" was realized with the students in the course Fundamentals of Architecture participated [6]. At the beginning and at the end of the courses, two tests were implemented: a Spatial Visualization task and an Abstract Reasoning task. Their results were compared with the control group of students enrolled in a Mathematics degree (without training in Technical Drawing). Although the difference was expected, improvements occurred in both groups; therefore, the conclusion was that this improvement was not due to indirect training.

The study of positive effects of three different types of teaching visual models (a 3D printed solid object, a 3D computer-generated drawing, and a 2D drawing) confirmed some differences [3]. The main results are the following: the 3D printed solid model and the 3D computer-generated image both provided statistically significant higher scores than the 2D drawing. While not statistically significant, the students who received treatment via the 3D-printed solid model outperformed their peers who received treatment from the other two models in the drawing. This could indicate that students could better comprehend visual data obtained from 3D solid models than from 3D computer-generated models or 2D drawings.

1.2. Technical drawing trainings and courses

Technical or engineering drawing skills are the formative skills for more activities of engineers in different engineering fields [18], because those skills are necessary for project documentation preparation, to sharing of different information using graphic languages (diagrams, schemes, and facilities, with a 2D drawing being the most frequently used), to deemed fundamental to graphic expression in professional practice. In many engineering professions, prospective and active engineers learn the rules of engineering communication through TD based on conventions and standards.

ED/TD courses can provide the context and tools for improving professional abilities and developing professional skills. The following reasons are emphasized [16]:

- It is a teachable area because it has a practical base in real-life situations organized according to occupational standards and drawing conventions;
- "The concrete experiences with geometrical objects and representing them in two-dimensional space are proved helpful in improving students' performance in spatial visualization" [16].

Development technical documentation is important part of TD courses. For communication to be unambiguous, it is necessary to follow valid standards when creating technical documentation. Standards in TD refer to the use of appropriate types of lines, the layout of projections, dimensioning rules, the definition of sections, the marking of surface quali-ty. For the correct interpretation of the drawing, the 3D model must be displayed accurately in the plane of the drawing with all visible and invisible edges. This is necessary in order to create a clear idea of the appearance of the 3D model presented in the drawing when reading the drawing. This means that engineers of all profiles should be able to present a 3D model in the plane of the paper and a 3D model in space based on 2D drawings.

The goal of the Technical Drawing Course for students-mechanical engineers is to make students technically literate, that is, to know all the rules and standards used to define machine parts on drawings. Also, they need to acquire the knowledge necessary for the successful presentation of machine parts and assemblies on TD and to be able to represent a 3D body based on a TD. Also, after the course, students can sketch a machine part or assembly, based on which a technical drawing can be made later. By studying the Auto CAD software, students are trained to draw with a computer, which speeds up the drawing process significantly. The mixed method of TD courses (teaching and learning manual technical drawing supported with digital tools) is the most present teaching methodology in this field today [19].

The knowledge the student acquires when he/she passes this course enables him/her to independently draw machine parts and assemblies on the appropriate drawings, with the necessary cross-sections, so that they are defined in terms of shape, dimensions, and machining. Students are trained to make drawings by hand and by computer.

2. RESEARCH METHODOLOGY

The goal of this paper is to highlight the connection between learning technical drawing and abilities development in a new educational context – a mixed teaching process with traditional tools of teaching and learning ED/TD and CAD. The tasks are to assess whether engineering students, who studied TD at the university level, improve their intellectual abilities, especially the effectiveness of the two very important cognitive processors: perceptive processors and cognitive processors. For these goals, the efficiency of the cognitive processors, defined in the framework of the cybernetic model of intellectual function [20], was investigated and used as a correlated phenomenon with the objectives of TD courses. The relationship between achievement in TD at the university level as a predictor or as an effect of TD courses will be explored in future research.

2.1. Variables

- Intellectual abilities: Based on the theoretical framework and model of intellectual functioning of the applied instrument/test and according to the authors of the instrument KOG3 [20], intelligence is: an adaptation ability, learning ability (learning speed, complexity of the operations which a person can learn) and abstract thinking (the ability to manipulate with the idea and symbols, using rules of education of the relation and correlates, reasoning, and deduction). According to this cybernetic model, intellectual ability is constituted by perceptive abilities (synthesis of perceptive analysis, perceptive structuring, and perceptive identify-cation), verbal comprehension, and visual spatialization (as an indicator of the factor of education and of the general intellectual factor).
- Initial skills of technical drawing: skills of technical drawing before attending the course of TD at higher educational institutions;
- Educational variables:
  - ✓ Type of pre-university education: mechanical vocational education, technical vocational education in the other fields (except for mechanical and mechatronics), nontechnical vocational education, general secondary education (grammar school);
  - ✓ Attending courses in TD and similar courses in secondary schools: with courses in the field of TD and without the courses in the field of TD (prior education in the field of TD and technics);
  - ✓ Results in Technical drawing exam after the course of technical drawing.

2.2. Method and techniques

Method: A quasi-experimental research used for the analysis of connections between learning technical drawing and the intellectual abilities of university engineering students. The research is realized in three phases:

(1) Collecting initial data about students' pre-university education, testing them by the test of intellectual ability and testing their initial knowledge and skills in the field of TD;

(2) Realization of the course: technical drawing and monitoring the process of students' learning technical drawing knowledge and skills during the TD course.

(3) Evaluation of the effects of TD courses: final measurements of intellectual ability and results on the exam.

Two connected exploratory pilot studies are realized and presented in the paper:

I The first study explores the correlations between students' abilities, pre-university educational variables, initial technical drawing skills, and results on the exams and pre-exam activities.

II The second study explores, based on initial research, the effects of a TD course on the students' abilities; the second study is in the case study format.

Techniques and instruments for data collection include:

1. Questionnaire of students' education and socio-demographic characteristics;
2. The cybernetic battery of intelligence tests KOG3 [20].
3. An initial test of technical drawing was constructed for this research.
4. The exam on the Technical Drawing Course.

The cybernetic battery of intelligence tests KOG3 [20] enables the evaluation of the efficiency of the functioning of the most important cognitive processors defined by the cybernetic model of intellectual functions. The battery consists of three tests of cognitive functioning, which assess the efficiency of the perceptual processor (IT-1 – image comparison test); the serial processor (AL-4 – verbal comprehension assessment test); and parallel processor (S-1 – test for measuring the ability to visualize spatial relationships) [21]. KOG3 battery was applied to the group of participants.

An initial test of TD was constructed for this research. The test of knowledge and skills in TD is a composite measure and consists of three groups of tasks with six examples each (Fig. 1, 2, 3 – next page). The maximum score is 18 points.

The first task is to match the displayed 3D models with the corresponding projections. This task is the most common task in TD, which is to define appropriate projections for a given 3D model. The students needed to combine one of the six offered 3D models with the corresponding projections.

The second task is to match the shown two projections with the missing third projection. Students should construct the third projection respecting the spatial relationships shown in the first two projections. Also, the height, length, and width of the 3D model must be the same in all projections. The six pairs of projections are given. The task is to match each pair of projections with the corresponding third projection.

In the third task, 3D models with different holes are given. It is necessary to find a suitable section for each 3D model. Respecting all the rules of technical drawing, it is needed to connect the displayed 3D models with the corresponding sections. The test of knowledge and skills in TD is a composite measure and consists of three groups of tasks (Fig. 1, 2, 3 / next page).

There is no correlation between the three groups of tasks. This result confirmed that the three groups of tasks measure different components of technical drawing skills. But all the task groups impact the general score (sum) and the correlations with the general score are very high (Table 1 - next page).

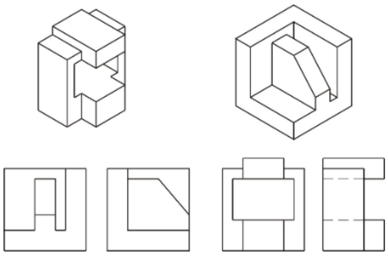

Figure 1. *Example of tasks 1*

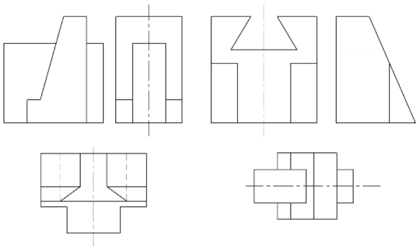

Figure 2. *Example of tasks 2*

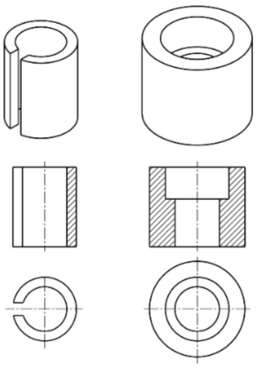

Figure 3. *Example of tasks 3*

Table 1. *Correlation matrix of the results on the technical drawing tasks*

	Tas7k 2	Task 3	Tasks sum
Task 1	0.24	0.07	0.50**
Task 2		0.26	0.89**
Task 3			0.58**
	N=46	** p< 0.01	* p< 0.05

The exam on the TD course consists of two parts. In the first part of the exam, it is necessary to present displayed 3D model in three projections, that is, to make a TD of the 3D model. The TD must be done by the standards. Also, the TD must be fully dimensionally defined. Surface roughness for each machined surface must be defined, as well as tolerances. In the second part of the exam, the task is to make a TD for a given 3D model, but in this part of the exam, AutoCAD is used. In this part of the exam, students' ability to present 3D models in projections is checked, as well as their knowledge of the rules of TD and capability to use AutoCAD for 2D drawings.

Techniques of data processing are based on the properties of small samples; descriptive statistics, correlation analysis, and analysis of variance are used.

2.3. Sample and procedures

The sample in the first study consists of 46 students, 20–21 years old, all undergraduate students in the first year of their studies in the engineering departments at the Faculty of Technical Sciences in Čačak at the University of Kragujevac in Serbia.

The sample in the second study (case study) involves 12 students in two departments (mechatronics and mechanical engineering), who passed the course Technical Drawing and participated in the initial and final testing.

Data collecting: March 2022 (Study 1) and March 2023 (second part of Study 2).

3. RESULTS AND DISCUSSION

This exploratory research was organized into two connected pilot studies.

3.1. Study 1

The first pilot study was realized as an initial investigation: collecting initial data about students' pre-university education, testing them by the test of intellectual ability, and testing their initial knowledge and skills of TD. Analysis of the main results in the first study confirmed the correlations between students' ability of space relationship visualization and achievement in the presentation 3D model task in three projections (table 2). Following this result, there is a correlation between the ability of space relationship visualization and the composite sum of three groups of tasks (r=0.34, p<0.05).

Table 2. *Correlation (r) of the KOG3 subtests and initial test (tasks) of technical drawing skills*

	Tasks 01	Tasks 02	Tasks 03	Tasks
Perceptual processing KOG3-IT-1	0.04	-0.05	-0.12	-0.07
Serial processing KOG3-AI-4	0.06	-0.11	-0.03	-0.07
Parallel processing KOG3-S-1	0.33*	0.27	-0.14	0.34*
Abilities KOG3 (Sum z score)	0.13	0.03	-0.01	0.08
Intellectual ability KOG3 IQ	0.20	0.05	0.00	0.09
	N=46	** p< 0.01	* p< 0.05	

Although "the research relative to engineering is centered on spatial skills, the mechanisms through which engineers may present a better spatial ability are not completely understood" [4]. Spatial skills are the focus of various research studies, but, the perceptual ability is the focus of this study, and increasing perceptual abilities based on perceptual processing is confirmed.

There are no differences in the measured abilities and results in the initial TD tasks between the students with different pre-university education (students from different vocational secondary schools and grammar schools).

3.2. Study 2

The second study focused on the measurement effects of the TD course on the students' cognitive abilities: the abilities of perceptual processing (visual-perceptual ability), serial processing (verbal comparison ability), and parallel processing (spatial ability or ability of space visualization).

Based on the results of the first study, 12 students were selected for this study, organized as research of a small educational group or case study. One year after the initial testing of students' cognitive abilities and six months after the course finishes and students pass the exam, the testing of students' cognitive abilities by the KOG3 battery is applied. Based on the ANOVA procedures for analyzing two measures on the same small sample, some differences were found (Table 3).

Students' abilities for perceptive processing are improved between two measurements, and composite intellectual ability (represented as IQ) is higher after a course and a passed exam than before attending TD courses. This result is highly significant.

Table 3. *Comparison* of the results of pre-course and post-course testing

Cognitive functioning KOG3	**Measurements** Pre-test Mean	Post-test Mean	F	Sig
Perceptual processing KOG3-IT-1 Max result 39	18.83	25.08	9.868	0.01**
Serial processing KOG3-Al-4 Max result 40	28.85	32.08	3.361	0.08
Parallel processing KOG3-S-1 Max result 30	23.17	24.17	0,181	0.67
N	12	12	F–Fischer coef.	
		** p< 0.01		* p< 0.05

So far, the researchers have analyzed connections between TD skills and the effectiveness of cognitive parallel processor (spatial ability in the KOG3) more often than the other connections. However, the results obtained in this study highlight the connections between TD skills and the effectiveness of perceptual processors.

Some research emphasizes that drawing and spatial ability have mutual connections: "drawing is dependent on spatial ability and spatial ability may be enhanced through learning to draw" [22]. Although the improvement in the ability to visualize spatial relationships in this research was expected, this cognitive function is stable between two measurements, and it is the same before and after the TD course. All of the selected students attended the TD course during pre-university vocational education in their middle and late adolescent period, and the effects of learning TD are formative for an earlier adolescent age [22]. The relationship between different forms of drawing and spatial and visual-perceptual ability, based on complex information processing, is very complex [9]. Consideration of the control condition of the effect of TD courses on the improvement the spatial and perceptual abilities [6]. Some explanation is the following: "Concrete experiences with geometrical objects and representing them in 2D space are proved helpful in improving students' performance in spatial visualization" [16].

The correlations between intellectual abilities improvement and results on the pre-exams and final exam are also analyzed. There are no correlations between the changes in intellectual abilities and students' results on the TD pre-exam and exam tests. The obtain result is significant for the course evaluation showing that the outcomes of the course and students' results on the exam (and pre-exam activities) are independent of the student's abilities. This result indicates that the realization of the TD course and the effectiveness of teaching differentiation and individualization as key to the additional value of education and the role of education to compensate for differences between students.

3.3. Teaching implications

What is the reason to improve intellectual skills during the TD course at the university and higher education level and based on TD activities?

The current tendency in education policy emphasizes the importance of middle and late adolescent's educational intervention for the improvement of their capacities. "It is a time for core programmes for abilities development" [22]. The first-year mechanical engineering students at the university are people in late adolescence. If there is an opportunity to develop abilities within the teaching process, it should be used because of the long-term effects and to increase efficiency.

What are the suggestions for TD teaching useful for broader transfer from the development of TD skills of students-mechanical engineers and to the development of their connected intellectual abilities? Although this research has limitations (a small sample, cognitive processing test standardized for a limited population), the comparison with the other research confirmed some educational implications.

Based on the researchers' evidence that "drawing and spatial abilities share common training" [9], on the constructivist theoretical approach, and on the review of the teaching and learning methods of TD courses and their effects [23, 24, 25, 26, 27], some suggestions to TD teaching formative for developing both technical drawing skills and perceptual and spatial abilities are the following:

- Using self-assessment of technical drawing skills and knowledge is a useful activity at the beginning of the TD course. This test provides students "with a tool for self-assessing their knowledge of the basic TD rules and principal standards and to give teachers some feedback on the different TD topics" [26]. The transfer from technical drawing skills development to the intellectual abilities connected with them is broader in this case.
- Using questionnaires of different students' opinions of technical topics related to technical drawing skills and competences and to possibilities to improve these skills. It is a tool for improving students' self-awareness in the field of TD.
- Using different teaching methods to increase students' motivation to learn TD [26].
- Using interactive self-learning tools for teaching TD, especially for teaching manufacturing dimensioning [26].
- Using 3D visualization tool-based training programmes for practicing mental rotation processes [28].
- Using student-centered education methods: include a continuous reflection process; appropriate different teaching and learning styles for the participants; recognize the diverse educational needs of the students; adapt their learning needs to their lives and professional experiences; allow the students to be involved in designing courses and control their own learning; improve students responsibility for learning; and involve cooperation between teachers and students [27].

4. CONCLUSIONS

The correlations between students' ability to visualize spatial relationships and presenting a 3D model in three projections are confirmed in this study. The students' perceptual processing abilities improve during the course of technical drawing, and composite intellectual ability (represented as IQ) is higher after a course and a passed exam than before attending TD courses. TD skills are correlated with some intellectual abilities and TD course is formative for some intellectual abilities.

Technical drawing courses consist of exercises in perceptual space recognition, too. In this research TD course have effects like the perceptual ability courses, because it consists of the acquisition of visual perception and spatial visualization skills, skills to interpret the 2D representation of 3D objects, manipulation, form development, and orthographic projections.

Enchasing students' abilities for perceptive processing and composite intellectual ability (represented as IQ) after a course is a highly significant research result. This result highlights the connections between technical drawing skills and the effectiveness of perceptual processors.

Technical drawing is a graphic language without boundaries. The main conclusion of this research is the importance of learning TD for the development of some perceptual spatial abilities. These abilities are one of the prerequisites for professional activity in the field of mechanical engineering. And the opportunity to improve these abilities is an important part of the education of mechanical engineering students for the most successful professional communication through technical drawings.

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REFERENCES

[1] Sutton, K., & Williams, A. (2007). Spatial cognition and its implications for design (IASDR07 – International Association of Societies of Design Research. The Hong Kong Polytechnic University).

[2] Ogunkola, B., & Knight, C. (2018). Does technical drawing increase students' mental rotation ability? *Cogent Education*, 5(1). 1489209. DOI: 10.1080/2331186X.2018.1489209

[3] Katsioloudis, P. J., & Jovanovic, V. (2014). Spatial visualization ability and impact of drafting models: A quasi experimental study. *Engineering Design Graphics Journal*, 78(2), 1–11.

[4] Mendez, M., Marin, S., Arias, N., Rubio, R., & Arias, J. L. (2014). Assessment of visual and memory components of spatial ability in engineering students who have studied technical drawing. *International Journal of Engineering Education*, 30(4), 806–812.

[5] Swanson, E. B. (1997). *An exploratory study: Reading and spatial visualization ability as predictors of success for technical drawing*. PhD diss.903. University of Northen Iowa. https://scholarworks.uni.edu/etd/903

[6] Contreras, M. J., Escrig, R., Prieto, G., & Elosúa, M. R. (2018). Spatial visualization ability improves with and without studying technical drawing. *Cognitive Processing*, 19(3), 387–397. https://doi.org/10.1007/s10339-018-0859-4

[7] Guo, J. W., Cao, X. C., Jin, J. J., & Wang, C. D. (2017). Development of engineering drawing ability for emerging engineering education, In *ICAMMT 2017, IOP Conference Series: Materials Science and Engineering*, 242(2017)012070. DOI:10.1088/1757-899X/242/1/012070

[8] Šafhalter, A., Glodež, S., Šorgo, A., & Ploj Virtič, M. (2022). Development of spatial thinking abilities in engineering 3D modeling course aimed at lower secondary students. *International Journal of Technology and Design Education*, 32(1), 167–184. https://doi.org/10.1007/s10798-020-09597-8

[9] Orde, B. J. (1997). Drawing as visual-perceptual and spatial ability training. *Proceedings of Selected Research and Development Presentations at the 1997 National Convention of the Association for Educational Communication and Technology (Albuquerque)* (pp. 271–277).

[10] Johnson, S. D. (1997). Learning Technological Concepts and Developing Intellectual Skills. In M. J. de Vries & A. Tamir (Eds.). *Shaping Concepts of Technology* (pp. 161-180). Dordrecht: Springer. https://doi.org/10.1007/978-94-011-5598-4_13

[11] Sternberg, R. J. (1983). Criteria for Intellectual Skills Training. *Educational Researcher*, (2), 6–26. https://doi.org/10.3102/0013189X012002006

[12] Sternberg, R. J. (1987). Teaching intelligence: The application of cognitive psychology to the improvement of intellectual skills. In J. B. Baron & R. J. Sternberg (Eds.). *Teaching thinking skills: Theory and practice* (pp. 182–218). Times Books, Henry Holt & Co.

[13] Tur, O., Shabunina, V., Butyrina, M., Tur, A., Krot, V., & Denys, M. (2021). Psychological and Educational Conditions for Developing Intellectual Competence of Electrical Engineering Students. IEEE International Conference on MEES (pp. 1–59). DOI: 10.1109/MEES52427.2021.9598774.

[14] Gardner, H. (1983). *Frames of mind: The theory of multiple intelligences*. New York: Basic Books.

[15] Gardner, H. (2020). The components of MI. MI Oasis. https://www.multipleintelligencesoasis.org

[16] Olkun, S. (2003). Making Connections: Improving Spatial Abilities with Engineering Drawing Activities. *International Journal of Mathematics Teaching and Learning*. DOI: 10.1501/0003624. Retrieved March 2023 from author's archive on ResearchGate

[17] Guzsvinecz, T., Orbán-Mihálykó, E., Perge, E., & Sik-Lányi, C. (2023). The Effect of Engineering Education on Spatial Ability in Virtual Environments. *Acta Polytechnica Hungarica*, 20(5), 11–30.

[18] Martinez, M. L., Carretero, A., Romero, G., & Mera, J. M. (2012). Evaluation and use of the standards in of the technical drawings in the final year project. *Procedia Social and Behavioral Sciences*, 2 (2012) 4239–4244.

[19] McLaren, S. V. (2008). Exploring perceptions and attitudes towards teaching and learning manual technical drawing in a digital age. *International Journal of Technology and Design Education*, 18, 167–188.

[20] Wolf, B., Momirović, K., & Džamonja, Z. (1992). *KOG-3 – Baterija testova inteligencije [KOG-3 – batery of the intellectual tests].* Beograd: Savez društava psihologa Srbije.

[21] Hrnjica, S., & Kovačević, P. (1995). Review: KOG3 battery of the test. Cybernetic battery of conative tests KON6 (In Serbian). *Psihologija*, 28(3–4), 401–406.

[22] Knoll, L. J., Fuhrmann, D., Sakhardende, A. L., Stamp, F., Speekenbrik, M., & Blakemore, S. J. (2016). A Window of Opportunity for Cognitive Training in Adolescence. *Psychological Science,* 27(12), 1620–1631. DOI: 10.1177/0956797616671327

[23] Adanez, G., & Velasco, A. (2002). Predicting academic success of engineering students in technical drawing from visualization test scores. *Journal of Geometry and Graphics*, 6(1), 99–109.

[24] Jarque-Bou, N., Roda-Sales, Plumed, R., & Gracia-Ibáñez, V. (2020). Estudio comparativo de metodologías de dibujo técnico para entrenar la visión espacial [Comparative study of technical drawing methodologies for spatial vision training], 24th International Congress on Project Management and Engineering, (Alcoi),10234.

[25] Motyl, B., Filippi, S., Baronio, G. & Speranza, D. (2021). Investigating Students' Perception on the Outcomes of Technical Drawing University Courses. In L. Roucoules, M. Paredes, B. Eynard, P. Morer Camo & C. Rizzi (Eds.). *Advances on Mechanics, Design Engineering and Manufacturing III. JCM 2020. Lecture Notes in Mechanical Engineering* (pp. 379–385). Springer, Cham. https://doi.org/10.1007/978-3-030-70566-4_60

[26] Speranza, D., Baronio, G., Motyl, B., Filippi, S., & Villa, V. (2017). Best practices in teaching technical drawing: experiences of collaboration in three Italian Universities. In B. Eynard, V. Nigrelli, S. Oliveri, G. Peris-Fajarnes & S. Rizzuti (Eds.). *Advances on Mechanics, Design Engineering and Manufacturing – Lecture Notes in Mechanical Engineering* (pp. 903–913). Springer, Cham. DOI 10.1007/978-3-319-45781-9_90.

[27] Toma, A. M., & Neculai, O. (2017). A new teaching method of technical drawing, *Journal of Industrial Desing and Engineering Graphics*, 12(1), 247–252. Retrieved May 26, 2023, from https://www.proquest.com/docview/1919409327

[28]Kadam, K., Mishra, S., Deep, A., & Iyer, S. (2012). Enhancing engineering drawing skills via fostering mental rotation processes, *European Journal of Engineering Education*, 46(5). 796–812. DOI: 10.1080/03043797. 2021.1920891