



Reconsidering technical drawing education in architecture: Analog and computer-based drawing toward a hybrid teaching model

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Abstract

In the environment of international higher education, many universities have transformed their educational programs for adapting to the digital turn. Recently, conventional architectural education has also adopted digital teaching methods, with the development of ever-changing technologies and the emergent environments such as disasters, pandemic environments and more. For planning the digitalization of architectural education, the article intends to query how technical drawing, as one of the methods of architectural representation, could be taught to novice students. The proposed model, a combination of computer-based and analog drawing methods, will contribute to the training of novice students by giving them the ability to think by drawing in the digital age. The impact of both drawing methods was investigated by conducting quantitative research in two student groups with the help of a questionnaire. The questionnaire includes close-ended questions to evaluate the advantages and drawbacks of the drawing tool over three main categories: course content, tools, and work environment.

This research project examines the learning methods of technical drawing course learning methods that are currently applied in a university and evaluates the convenience of computer-based and analog drawing methods on the learning outcomes of the course. This research project presents the merits of analog and computer-based drawing methods considering the course contents, learning tools and work environment, and constitutes a knowledge base for the hybrid curriculum.

Highlights

- In order to overcome the difficulties of analog drawing for the architectural representation course in higher education throughout the Covid-19 pandemic, a hybrid teaching model, which combines analog and digital drawings was proposed.
- Proposed hybrid teaching model could be the first step to reach to the complete digitalization of architectural representation course for the first-year students.
- The effects of both analog and digital drawings were evaluated by the help of a survey that designed in three categories; course contents, learning tools and work environment.
- A progressive experimental model from analog drawing to digital drawing in architectural representation course could be contributed to improve curriculum in the process of digitalization.

Keywords

Covid-19; Architectural representation; Analog drawing; Digital drawing; Teaching model.

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Mimarlıkta teknik çizim eğitimi yeniden düşünmek: Melez bir öğretim modeline doğru analog ve bilgisayar tabanlı çizim

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Öz

Uluslararası yükseköğretim ortamında, birçok üniversite dijital dönüşüme uyum sağlamak için eğitim programlarını dönüştürmüştür. Son zamanlarda, sürekli değişen teknolojilerin gelişmesi ve afetler, pandemi ortamları gibi ortaya çıkan ortamlarla birlikte, geleneksel mimarlık eğitimi de dijital öğretim yöntemlerini benimsemiştir. Mimarlık eğitiminin dijitalleşmesini planlamak için, bu makale, mimari temsil yöntemlerinden biri olan teknik çizimin yeni başlayan öğrencilere nasıl öğretilebileceğini sorgulamayı amaçlamaktadır. Bilgisayar tabanlı ve analog çizim yöntemlerinin bir kombinasyonu olan önerilen model, yeni başlayan öğrencilere dijital çağda çizim yoluyla düşünme yeteneği kazandırarak eğitimlerine katkıda bulunacaktır. Her iki çizim yönteminin etkisi, bir anket yardımıyla iki öğrenci grubunda nicel araştırma yapılarak incelenmiştir. Anket, üç ana kategoride (ders içeriği, araçlar ve çalışma ortamı) çizim aracının avantajlarını ve dezavantajlarını değerlendirmek için kapalı uçlu sorular içermektedir.

Bu araştırma projesi, bir üniversitede halihazırda uygulanan teknik çizim dersinin öğrenme yöntemlerini incelemekte ve bilgisayar tabanlı ve analog çizim yöntemlerinin dersin öğrenme çıktıları üzerindeki uygunluğunu değerlendirmektedir. Bu araştırma projesi, ders içeriği, öğrenme araçları ve çalışma ortamını dikkate alarak analog ve bilgisayar tabanlı çizim yöntemlerinin avantajlarını sunmakta ve hibrit müfredat için bir bilgi tabanı oluşturmaktadır.

Öne Çıkanlar

- Covid-19 pandemisi boyunca yükseköğretimdeki mimari temsil dersinde analog çizimin zorluklarının üstesinden gelmek amacıyla, analog ve dijital çizimleri birleştiren melez bir öğretim modeli önerilmiştir.
- Önerilen melez öğretim modeli, birinci sınıf öğrencileri için mimari temsil dersinin tamamen dijitalleştirilmesine yönelik ilk adım olabilir.
- Hem analog hem de dijital çizimlerin etkileri, ders içeriği, öğrenme araçları ve çalışma ortamı olmak üzere üç kategoriye ayrılmış bir anket yardımıyla değerlendirilmiştir.
- Mimari temsil dersinde analog çizimden dijital çizime doğru ilerleyen deneysel bir model, dijitalleşme sürecinde müfredatın geliştirilmesine katkıda bulunabilir.

Anahtar Sözcükler

Covid-19; Mimari temsil; Analog Çizim; Dijital çizim; Öğretim modeli.

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INTRODUCTION

With the Covid-19 pandemic, many universities had to maintain their education on online platforms. Although architecture is a discipline that requires face-to-face interaction, the crisis caused by the Covid-19 pandemic is planned to be overcome with well-structured online courses. The shift from face-to-face education to online education profoundly affects many programs (Hodges et al., 2020, 2), especially those that have applied/laboratory courses in the disciplines of architecture and engineering, since these courses mostly depend on visual communication, in studio interaction, and hands-on production. In architectural education, the Technical Drawing course is one of the courses in which this transformation became critical, because its content has traditionally been taught through analog drawing methods and face-to-face instruction. In this context, the research project was developed to examine how the content of the Technical Drawing course could be adapted to online education through computer-based drawing. The project did not only aim to respond to the conditions of the Covid-19 period, but also to understand the potential and limitations of computer-based drawing tools in relation to course content, drawing practice, and work environment. This article aims to evaluate the teaching efficiency of the analog and computer-based drawing methods based on the students' perceived learning and discusses how these findings may provide a basis for a hybrid teaching model in first-year Technical Drawing education. As well-known, drawing is used as a way of thinking tool in the discipline of architecture. After the digital turn, it has become substantial to teach both analog (hand drafting drawing) and computer-based (drawing by computer) drawing techniques/methods. On the occasion of the research project, a radical shift from analog drawing towards the computer-based drawing for the architectural curriculum of first-year students was proposed. At this point, it is significant to inform that the developed teaching model is directly enhanced to be an Effective Online Education rather than an Emergency Remote Teaching model (Hodges et al., 2020).

THEORETICAL BACKGROUND OF ARCHITECTURAL DRAWING

The Act of Drawing in Architecture

Visual representation exists in many design disciplines as a final output that includes design features and implementation procedures (Goldschmidt, 2017, 77). People exchange information, learn and communicate by sharing their mental models (Goldschmidt, 2017); in many disciplines, the exchange of these shared mental models and the act of learning is achieved through "language". However, in architecture and similar design disciplines, the exchange of the "shared mental model", which provides the act of learning, takes place through visual representations and images (Goldschmidt, 2017, 94). Therefore, in architectural education, the student's ability to develop a

visual representation both enables him/her to externalize his/her mental/imaginary design, and to share/transfer information with his/her instructor via this representation. Ultimately, visual representation achieved by act of drawing is a communication model that encounters two brains and permits sharing thoughts. Unlike digital tools, hand-drawing is an irreplaceable cognitive tool that operates imprecise and open medium for intuitive exploration (Yıldızoğlu, 2024).

The act of drawing cannot be considered as an end product; architectural representations are a part of the architectural thought process and provide interaction between the brain, eye, and hand. There are three main types of architectural representation methods: “referential sketch”, “preparatory study” and “definitive drawing” (Graves, 2012). Since the “definitive drawing” represents the final product, it can be expressed via computer, but the referential sketch and preparatory study used in the process belong to the process of architectural thought and play an active role in creativity (Graves, 2012). For Ceylan et al. (2024), using digital tools without adequate pedagogical scaffolding in early stages of design studio can weaken spatial understanding of students. However, teaching/making technical drawing could be evaluated as in the type of definitive drawing that represent the final architectural product, which necessitates geometric precision. At this point, it is possible to hybridize hand-drawing and computer-based drawing for introducing technical drawing course in the period of pandemic in order to overcome the problems of medium convergence.

Comparison of Analog and Computer-based Drawing Methods

Visualisation has a significant role as an essential tool in the communication process of architectural design (Caldwell & Woodward, 2012, 989). Visualisation is an active mechanism in the design process, from the production and representation of initial design information to the final revelation of design documentation (Caldwell & Woodward, 2012, 990). For Aguilar Zavaleta (2026), graphic representation in architecture is a communication method that constitutes the language through which architectural thought is materialized, discussed and transmitted before becoming a building. Replacement of analog drawing with digital tools was not a linear but a progressive path since 1980, when the digital tools were introduced to architectural design progress (Aguilar Zavaleta, 2026). Until 1980, visualization/graphic representation in architecture based exclusively on manual tracing; after 1980, it was transformed by the incorporation of computer-based drawing, and recently (after 2021) it has been at the revolutionary threshold with generative artificial intelligence (AI) models (Aguilar Zavaleta, 2026). More recent improvements in architectural visualization with generative artificial intelligence (AI) models are out of scope of this article. The article that based on the research project, which covers the teaching of the Technical Drawing course during pandemic period, mainly focused on hybridization process of hand-drawing and computer-based drawing of the course.

Visual communication in design could be taught in three types of representation modes: analogue, digital, and the hybridisation of both mediums (Ibrahim & Pour Rahimian, 2010). The analogue mode generally articulated by freehand or manual drafted/crafted methods (Brandon & McLain-Kark, 2001). In the digital mode, some form of human-computer interaction is observed, such as Computer Aided Software (CAD) and/or Virtual Reality (VR) tools (Brandon & McLain-Kark, 2001; Ibrahim & Pour Rahimian, 2010). The hybridisation mode is a new pedagogical method,

which is created for post-digital designers (Caldwell & Woodward, 2012, 990). More creative and innovative forms of visualization could be observed through the use of hybridisation of media in the design process; design students are able to develop their own techniques via this hybrid approach (Caldwell & Woodward, 2012, 993). Introducing the principles of analogue and digital visualisation techniques have critical importance for design students in order to explore the potentials and possibilities of hybridization method (Caldwell & Woodward, 2012, 993).

Wang and Pan (2013) presented a proposal that supports both hand and computer drawing for the Engineering Graphics course, which has a similar content to the Technical Drawing course. Accordingly, if there is no manual drawing education, the student will not have the ability to interpret drawings and will have difficulties in drawing, expressing, and editing via computer. In this context, the primary goal of the Technical Drawing Course in the first-year architecture curriculum is to enable the student to learn the architectural/visual representation methods that will make the production in his/her mind visible.

It is possible to produce visual representations both with analog and digital methods in the current era. The advantages of hand drawing (analog method), used as a thinking tool instead of a computer (digital method), are fast production which is realized in parallelization with the flow of thought, production with minimized rules, allowing incompleteness and blurriness, recycling ease and flexibility (Goldschmidt, 2017, 82). Brandon and McLain-Kark (2001) expressed the positive aspects of both methods in their study; hand drawing is important for the designer to be able to constitute direct relationships between his/her mental images and graphic representations, to be flexible, and to think overlap drawings. On the other hand, computer drawing has also a potential in many ways, such as easily orienting the design (scale, zoom, copy and rotate), producing overlapping drawings with multiple views and layering system, and providing three-dimensional images.

Carpo (2011) divides the act of designing by drawing into three technical eras; manual making (hand making), mechanical making, and digital making. From the Renaissance to the digital age, drawing was seen as the basis of the act of creating; so much so that, according to Alberti's design theory, the physical structure following the drawing is a replica devoid of intellectual added value (Carpo, 2013, 128). According to Alberti's paradigm, it is possible to divide architectural drawings into two; the representational — the direct transference of the mental situation — and the notational — the precise transfers to be used for production (Carpo, 2013, p.129). In the digital age, it is possible to produce not only two-dimensional but also three-dimensional representational drawings in the computer environment/space, except for the two-dimensional environment of paper. It is also possible to produce the notational script completely digitally and send the file directly to production (Carpo, 2013, 133)

Before technological developments in drawing tools, notational drawings were mainly produced through hand drawing in conventional architectural education. However, today, there are various options to produce notational drawings for architectural communication and production. How the Technical Drawing course taught is mainly related to the pedagogical structure and priorities of architectural curriculum. Within this research project, which was conducted during the pandemic period, the hybridization of digital and analog mediums was considered in response to the changing

conditions of technical drawing education. During the pandemic process, the Technical Drawing course had to be conducted on digital platforms. This situation required a change in the teaching model of the course, because transferring analog drawings to digital platforms through photographic techniques weakened the quality of drawings, feedback, and evaluation. Therefore, computer-based drawing lectures were added in parallel with the existing course syllabus, without changing the main content of the course. Since analog and computer-based drawing methods were applied in separate student groups, the study primarily compared students' evaluations of these two drawing methods. In this sense, the findings provided a basis for developing a more comprehensive hybrid teaching model for Technical Drawing education.

MATERIAL AND METHODS

To conduct the Technical Drawing course in the architecture discipline, the research project that combines analog and computer-based drawing methods were suggested and tested on first-year students. during the Covid-19 pandemic, for giving a start to hybrid model in the curriculum, which is capable to adapt itself to current digitalization processes. The project mainly suggests a newly organized teaching model that juxtaposed two methods, drawing by hand and by computer, to teach the curriculum of technical drawing. The reason behind the changing methodology of teaching technical drawing is that the online learning environment does not permit an evaluation of some course contents (such as scale understanding). Additionally, to decrease/minimize media conversions (such as from paper to photography, from photography to screen), this base for hybrid method is proposed. To understand the prominent features of both drawing methods and to evaluate the outcomes of the research project, a questionnaire is conducted on two groups of students who are in the same semester; the first group of students took the course on face-to-face education by analog drawing method, the second group of students took the course on online education by computer-based drawing method.

Significance of the Research Project

Drawing is a natural and fundamental human action (Fascari, 2011). Whether it is done by hand or with a computer, thinking by drawing is an indispensable basic method in the discipline of architecture. Fascari (2011, 3) defines the significance of drawing like that "As both a communication contrivance and a conceptual implement, the act and making of drawings is essential to all facets of the architectural process." The conceiving process of the importance of the act of drawing for an architect is improved and given to the students during their architectural education. To enable expression of the architectural ideation, students are taught to act/make drawings in rules and norms within the drawing course. The technical drawing course is taken place in the first year of the curriculum of architectural education, and the content of the course is mostly taught by analog method (by hand drawing). In the case of this research project, the content has already been given by hand drawing methodology until last semester the Covid 19 pandemic released. Covid-19 pandemic forces educators to reorganize/adapt the methodology of the technical drawing course to online education.

The situation that gives the project its unique value is that the content of the technical drawing course is taught to first-year students via using the computer drawing method during online education. The choice of digital drawing techniques (from hand drawing to computer drawing) enabled educators to overcome the difficulties of online education. So much so that with the application of this hybrid method, first-year students learned both to draw by hand and to be familiar with the representation method of drawing in a completely digital environment. The proposed research project is a unique way to handle the frequency and difficulty of changing the drawing/design environments in online education. It is seen that a work produced with the conventional analog drawing method is not easily converted to be shared on digital online learning platforms. Thus, to solve the limitations of paperwork during online education, it is unavoidable to suggest direct production in the digital design environment. The problem in the operation, switching the process from taking a photograph of the hand drawing to sharing the screen of the digital design space, is handled and resolved with the help of the research project. The research project made it possible to combine/organize the content of the technical drawing course and the drawing medium on online learning platforms; rather than using paper, the computer was selected as the drawing medium to teach the course content of the technical drawing.

Structure of the Research Project

In the teaching method proposed/experienced on online platforms during the pandemic period, for the hybridization of analog and computer based drawing, mainly two groups of lectures were constructed in Technical Drawing Course; the first group of lectures contains the essential knowledge/information about norms and rules of technical drawing, the second group of lectures consists of AutoCAD education, which was structured to give basic skills. As the content of the technical drawing course, six fundamental lectures, which are supported with AutoCAD education lectures, were conducted. These lectures contain the knowledge of “Line Types and Line Quality”, “Lettering”, “Orthographic Projection (Multiview Drawings)”, “Scale”, “Section”, and “Paraline Drawings”. Abovementioned subjects were given students in both drawing methods via the help of two set of the lectures, which are conducted to parallel to each other. Exercises as homework were designated to consolidate the lectures.

In order to evaluate conducted lectures, the verbal expressions in Bloom’s Taxonomy were used in the questionnaire. Bloom’s Taxonomy was structured for generating a common language to assess the learning/teaching outcomes. The original taxonomy was formed under the six major categories in cognitive domain, which were Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation, at 1949 and published at 1956. After 45 years later, The Bloom’s Taxonomy is revised by David R. Krathwohl (2002); three categories were renamed, the order of two was interchanged and the category of Knowledge was changed into a verb form. The final revised Bloom’s categories, which are cumulatively framed in the verbal form, are Remember, Understand, Apply, Analyze, Evaluate and Create (Krathwohl, 2002). The revised Bloom’s taxonomy was articulated to the questionnaire of the research project, in order to develop standardized learning objectives.

DATA COLLECTION AND ANALYSIS

Data collection

The study includes the quantitative research method. Data was collected with the questionnaire survey [University Scientific Research and Publication Ethics Committee, Date: 23.02.2021, Permit No: 31] and analyzed with the SPSS v.28. statistical analysis program. Participants voluntarily involved in the research project's questionnaire. The questionnaire did not request any personally identifiable information, and all responses were collected anonymously. Informed written consent (with the informative section about the study) to take part in was obtained electronically before the commencement of questionnaire. The questionnaire was explained to the students, and it is conducted for both groups in morning and afternoon sessions on the Zoom platform (as to be completed in 10 to 15 min). A questionnaire is preferred as a research method because it enables the objective means to gather information from people to understand their knowledge, beliefs and attitudes, and behavior (Boynton and Greenhalgh, 2004). The questionnaire (prepared bilingual, in Turkish and English) includes close-ended questions to evaluate the advantages and drawbacks of the drawing tool (analog/computer-based) in developing the drawing understanding over three main categories: course content, tools, and work environment. The close-ended questions were evaluated with a five-point scale ranking system. In addition to the main body of the questionnaire, the socio-demographic section is added to understand the demographic distribution of the students. While the course content section is developed to evaluate the competency in the important subject titles of the technical drawing course's curriculum (line-lettering, multiview drawings, scale, section, and paraline drawings), the tools section intends to appraise the strengths and weaknesses in each drawing tool. Finally, the last section (work environment) seeks to understand the relationship between the work environment and the selected drawing tool.

Data analysis

The questionnaire was used to collect data for analysis. The data analysis is conducted by using the statistical software program IBM SPSS Statistics v.28. (IBM Corp., 2021). Collected data was evaluated and carelessly filled questionnaires were eliminated from the data. Then, the survey's reliability was checked with the value of Cronbach's alpha for both experimental groups. According to these values, 87% in the computer drawing group and 86% in the analog drawing group were found. Both values reflect a high strong consistency between the questions. Questions were evaluated to understand whether the distribution of the data is normal or not with Kolmogorov-Smirnov the test of normality. In both experimental groups, it was found that data is not normally distributed ($p < 0.05$). To understand the statistically significant differences between two conditions in which different participants have been used, the Mann-Whitney U test was decided to run as a non-parametric test. Lastly, Spearman's rho (r_s) Correlation test was used to analyze the dependency between questions since the variables of the questions were measured at an ordinal level.

RESULTS AND DISCUSSION

Experimental Groups

Data was gathered through an online questionnaire. Students participated voluntarily in the study in the Computer Drawing Group (CDG) and Analog Drawing Group (ADG). The two experiment groups differ in terms of both their drawing tool usage and educational model. Based on that, the first group (n=49) includes the students that learns computer drawing tool in an online educational model whilst the students of the second group (n=49) took their drawing education with analog drawing tool in the face-to-face educational model. The courses for both groups were delivered by the same instructors. The demographic distribution of students was recorded for gender as 75 females (76.5%) and 23 males (23.5%) and for age as between 18-24 years (93.9%) and between 25-30 years (6.1%). The majority of the students had taken the technical drawing course for the first time (68.4%) (Table 1).

Table 1. Socio-demographic distribution of the students in experimental groups (n=98)

Socio-demographic Results	Frequency (n)	Percentage (%)
Gender		
Female	75	76.5
Male	23	23.5
Age		
18-24	92	93.9
25-30	6	6.1
The number of enrollments to Technical Drawing Course		
First time	67	68.4
More than one	31	31.6

Differences between experimental groups

During the analysis of the results, the aim was to present the different aspects of each drawing tool to develop an educational model for both online and face-to-face education. The questionnaire includes three sections on the main body. In the first section, the questions were selected to match the syllabus of the course to understand whether students gain the basic concepts of the course in the selected educational model tool. The syllabus of the course was conducted with the same content in both experimental groups. Based on that, the frequency analysis and Mann-Whitney U test were conducted. In a frequency distribution, the students' self-evaluation regarding the course content was aimed to understand, and with the Mann-Whitney U test, the differences between the two condition groups were revealed. The results of these tests were combined in the following tables (Table 2,3,4).

Table 2. Frequency analysis and Mann-Whitney U test results of Content section

Questions (Section: Content)	Syllabus Category	Bloom's Taxonomy	Group	Evaluation		
				Disagree	Neutral	Agree
Q.2.1. It took me a while to adapt to the equipment of the drawing tool.	Tools	Apply	CDG	32.7	20.4	46.9
			ADG	44.9	20.4	34.7
Q.2.2. The working environment of the drawing tool (paper / computer) made me easily get used to the drawing technique.	Tools	Apply	CDG	10.2	26.5	63.3
			ADG	10.2	24.5	65.3
Q.2.3. I understood the expression of different types of lines in drawing with drawing tool I use.	Line & Lettering	Understand	CDG	4.1	16.3	79.6
			ADG	2	6.2	91.8
Q.2.4. The drawing tool has made it easy to apply different line thickness in drawing.*	Line & Lettering	Apply	CDG	10.2	0	89.8
			ADG	20.4	6.1	73.5
Q.2.5. With this drawing tool, I can easily generate lines that are parallel, perpendicular to each other, or intersect at various angles.*	Line & Lettering	Apply	CDG	0	6.1	93.9
			ADG	14.3	6.1	79.6
Q.2.6. I was able to comprehend three-dimensional objects and understand their expression in two dimensions with drawing tool I use.	Multiview Drawings	Analyze	CDG	4	8.2	87.8
			ADG	12.2	4.1	83.7
Q.2.7. I understood the application of the scale in the drawing tool I use.	Scale	Apply	CDG	6.1	16.3	77.6
			ADG	6.1	6.1	87.8
Q.2.8. I realized that the scale is directly related to the drawing environment.*	Scale	Evaluate	CDG	10.2	14.3	75.5
			ADG	6.1	2.1	91.8
Q.2.9. I can easily notice the details at different points of the drawing.	Scale	Evaluate	CDG	4.1	26.5	69.4
			ADG	10.2	12.2	77.6
Q.2.10. The drawing tool made it easy for me to understand what I should see while taking the section of the objects.	Section	Analyze	CDG	6.1	8.2	85.7
			ADG	4.1	10.2	85.7
Q.2.11. The drawing tool made it easy to produce three-dimensional objects.*	Parallel Drawings	Create	CDG	10.2	8.2	81.6
			ADG	26.5	16.4	57.1
Q.2.12. The drawing tool made it easy for me to understand the structure of three-dimensional objects.	Parallel Drawings	Analyze	CDG	8.2	20.4	71.4
			ADG	22.4	22.5	55.1

Blue indicates Computer Drawing Group whilst Gray indicates Analog Drawing Group

The questions that have statistically significant differences between two drawing groups are indicated with (*)

The 5-scale evaluation results were recoded into 3-scale as disagree, neutral, and agree to convey the information in a simple way. The keyword/ syllabus category of each question was given in the tables (Table 2,3,4). In Table 2, each question was associated with a corresponding Bloom's taxonomy action verb to clarify the cognitive level addressed by the item and its relation to the course content.

According to the results of the frequency test, the Content section reveals that students get the educational base of the course in both drawing tools because students agreed with almost all questions that evaluate their understanding regarding different topics of the course. In Table 2, the majority of the answers with percentages were indicated for each question. Even if the distribution of the students' answers differs in these questions, the majority of the students in each question evaluated the content questions similarly in both groups. According to the Mann-Whitney U test, there are statistically significant differences between the three questions, which are indicated with (*) in Table 2. A higher proportion of CDG students (89.8%) agreed that the drawing tool they used made it easy to apply different line thicknesses, compared with ADG students (73.5%) ($p < 0.001$, $U = 720$, $z = -3.800$, $r = -0.38$). Similarly, CDG students reported more positive evaluations than ADG students regarding the generation of lines that are parallel, perpendicular, or intersect at various angles (93.9% and 79.6%, respectively) ($p < 0.001$, $U = 683$, $z = -4.330$, $r = -0.44$). In contrast, the ease of producing three-dimensional objects was evaluated more positively by ADG students (91.8%) than by CDG students (75.5%) ($p < 0.001$, $U = 832$, $z = -2.746$, $r = -0.28$). These differences indicate that each drawing tool was perceived to support different aspects of technical drawing practice: the computer-based tool was associated with precision and controlled line production, whereas the analog tool was evaluated more positively in relation to three-dimensional object production. Overall, the results suggest that both drawing tools supported students' engagement with the main contents of the course and contributed, in different ways, to their perceived understanding of three-dimensional objects and their two-dimensional representation.

The second section of the questionnaire, Tools which is presented in Table 3 with corresponding keywords, focused on the perceived affordances and limitations of each drawing tool. The Mann-Whitney U test revealed statistically significant differences for several aspects of tools. The Mann-Whitney U test results showed that the time efficiency aspect was evaluated differently in both experimental groups. CDG students (75.5%) believed that they can produce by using time efficiently ($p < 0.001$, $U = 614$, $z = -4.636$, $r = -0.46$) with the tool they are using while ADG students (49%) evaluated this aspect negatively. A similar pattern was observed for practical use, with 87.8% of CDG students giving positive responses, compared with 49% of ADG students giving negative responses ($p < 0.001$, $U = 585$, $z = -5.131$, $r = -0.51$).

Table 3. Frequency analysis and Mann-Whitney U test results of Tools section

Questions (Section: Tools)		Question Keyword	Group	Evaluation		
				Disagree	Neutral	Agree
Q.3.1.	I can produce by using time efficiently with the drawing tool I use. *	Time Efficiency	CDG	6.1	18.4	75.5
			ADG	49	16.3	34.7
Q.3.2.	I think the drawing tool I use provides practical use.*	Practical Use	CDG	6.1	6.1	87.8
			ADG	49	12.2	38.8
Q.3.3.	The drawing tool I use makes me physically tired.*	Physically Tired	CDG	32.7	26.5	40.8
			ADG	16.3	2	81.7
Q.3.4.	The drawing tool I use makes me mentally tired.	Mentally Tired	CDG	26.5	26.6	46.9
			ADG	20.4	16.3	63.3
Q.3.5.	I think the drawing tool I use contributed to my learning.	Contribution to Learning	CDG	4.1	6.1	89.8
			ADG	4.1	8.1	87.8
Q.3.6.	I enjoy the drawing tool I use*.	Enjoyment of Drawing	CDG	6.1	8.2	85.7
			ADG	18.4	24.5	57.1
Q.3.7.	I can produce quickly with the drawing tool I use.*	Agility of Production	CDG	6.1	6.1	87.8
			ADG	49	16.3	34.7
Q.3.8.	I believe I have advanced my skills in this drawing tool.	Advancement on Skills	CDG	6.1	12.3	81.6
			ADG	6.1	10.2	83.7
Q.3.9.	I believe I have advanced my three-dimensional thinking ability in this drawing tool.	Advancement on 3D thinking	CDG	6.1	22.5	71.4
			ADG	12.2	26.6	61.2
Q.3.10.	I could easily spot my mistakes with the drawing tool I use.	Spot the Mistakes	CDG	6.1	24.5	69.4
			ADG	8.2	20.4	71.4
Q.3.11.	I was able to correct my mistakes quickly with the drawing tool I use.*	Correct the Mistakes	CDG	4.1	10.2	85.7
			ADG	46.9	8.2	44.9
Q.3.12.	This drawing tool makes it easy to archive my drawings.*	Ease of Archive	CDG	2	10.2	87.8
			ADG	40.8	20.4	38.8
Q.3.13.	With the drawing tool I used, I needed less feedback on my drawings.	Less Feedback	CDG	22.4	32.7	44.9
			ADG	40.8	26.5	32.7

Blue indicates Computer Drawing Group whilst Gray indicates Analog Drawing Group

The questions that have statistically significant differences between two drawing groups are indicated with (*)

In contrast, physical tiredness was more strongly associated with the analog drawing tool: 81.6% of ADG students agreed that the tool made them physically tired, compared with 40.8% of CDG students ($p < 0.001$, $U = 754$, $z = -3.652$, $r = -0.36$). Enjoyment of drawing ($p=0.002$, $U=857$, $z=-3.072$, $r = -0.31$) was associated with both groups positively as in CDG (85.7%) and ADG (%57.1).. CDG students also reported more favorable evaluations of production speed, with 87.8% agreeing that they could produce quickly, while 49% of ADG students evaluated this item positively ($p < 0.001$, $U = 539$, $z = -5.429$, $r = -0.54$). Quick correction to the mistakes ($p<0.001$, $U=657$, $z=-4.602$, $r = -0.46$) was found mostly positively associated with students in CDG (%85.7) and negatively with students in ADG (%46.9). Lastly, students in CDG (%87.8) evaluated that their drawing tool enables easy archiving ($p<0.001$, $U=567$, $z=-5.252$, $r = -0.53$) whilst students in ADG (%40.8) evaluated that the analog drawing tool does not support easy archiving.

The frequency distribution of the remaining questions in the Tools section is presented in Table 3. In general, the results showed that computer drawing tool was perceived more positively in relation to time efficiency, practical use, the agility of production, easy spot to mistakes, quick correction to mistakes, and ease of archive. However, it was also associated with physical and mental fatigue.

The analog drawing tool was more frequently associated with time-consuming, limited practicality, physical and mental fatigue, slow production, easy spot to mistakes, slow correction to mistakes, and archive difficulty, although students also reported that it allowed them to identify mistakes. In both groups, students evaluated their drawing tools positively in terms of their perceived contribution to learning, enjoyment of drawing, advancement of the drawing skills, and improvement of 3D thinking ability. In addition to that the responses regarding the need for feedback were more evenly distributed across the three response categories in both groups, indicating that this aspect was not strongly associated with either drawing tool. Instead, feedback requirements may depend more on individual student preferences, student learning habits, and perceived complexity of the task.

The last section includes questions related to the Work Environment of the drawing tools (Table 4). Students in CDG (%46.9) did not agree with the phrase 'the physical environment in which I worked negatively affected my competence in the drawing tool' ($p=0.007$, $U=867$, $z=-2.675$, $r = -0.27$) whilst the majority of the students in ADG (%81.6) agreed. In addition to that, the students in CDG (%73.5) stated that they do not need a specific work environment for the drawing tool they are using whilst almost half of the students in ADG (%42.9) stated no requirement for a specific work environment for their drawing tool ($p<0.001$, $U=642$, $z=-4.550$, $r = -0.45$). The participation to the class did not differ in both groups which shows that participation to the class is mostly related to the student's wishes rather than the physical environment they are in.

Table 4. Frequency analysis and Mann-Whitney U test results of Work Environment section

Questions (Section: Work Environment)		Question Keyword	Group	Evaluation		
				Disagree	Neutral	Agree
Q.4.1.	The physical environment in which I worked negatively affected my competence in the drawing tool.*	Drawing Competency and Environment	CDG	46.9	14.3	38.8
			ADG	8.1	10.3	81.6
Q.4.2.	The physical environment I was in negatively affected my participation to the class.	Participation to the Class	CDG	40.8	16.3	42.9
			ADG	32.7	24.4	42.9
Q.4.3.	I need a specific working environment in this drawing tool.*	Independency of The Environment	CDG	73.5	10.2	16.3
			ADG	42.9	32.7	24.4

Blue indicates Computer Drawing Group whilst Gray indicates Analog Drawing Group

The questions that have statistically significant differences between two drawing groups are indicated with (*)

In this section, it is understood that the relationship between the physical work environment and drawing competency was evaluated differently by the two experimental groups. Although the Covid-19 period created the condition for conducting the course online and using computer-based drawing, the results should not be interpreted only as an effect of the pandemic. CDG students mostly evaluated their drawing competency as less dependent on the physical work environment. This tendency was also observed in the requirement of a specific work environment for CDG students, which may be related to the flexible and portable structure of the computer drawing tool.

On the other hand, ADG students evaluated the need for specific working environments with almost equal distribution between the evaluation scales. It was also observed that most of the analog drawing students evaluated the physical environment as a negative effect on their competence in the drawing tool. This result may be related to the material and spatial requirements of analog drawing, such as drawing equipment, desk conditions, lighting, and the need for a stable workspace. However, since CDG students took the course online and ADG students took the course face to face, the effects of the drawing tool and the educational setting cannot be fully separated.

To conclude, it is interpreted the two groups did not show a clear difference in their perceived engagement with the main contents of the course. Rather, they differ mostly in the selection of drawing tool and the work environment.

Correlations in experimental groups

The correlation between questions in the tool section had been investigated to understand the effects of aspects of drawing tools on course learning outcomes. Evaluation of the course learning outcomes was aimed to be analyzed with the phrase 'I think the drawing tool I use contributed to my learning' that is associated with the keyword 'contribution to learning' (Table 5). In CDG, contribution to learning was found to have a significant positive correlation with many keywords such as time efficiency, practical use, the agility of production, the spot of the mistakes, and quick

correction of the mistakes. It can be interpreted that when the drawing tool was perceived as enabling time efficiency, practical use, the agility of production, and easy identification and correction of mistakes, students also evaluated its contribution to learning more positively. It is also valid for the dependencies between the enjoyment of drawing, advancement of drawing skills, and advancement of 3D thinking ability and contribution to learning. If students enjoy the act of drawing, and advance in both drawing skills and 3D thinking ability, they tend to report a stronger contribution of the drawing tool to their learning.

Table 5. Results of Spearman's rho (r_s) Correlation test for the dependency between questions in Tools section

Computer Drawing Group			
Questions (as Keywords)	r_s	p	n
Contribution to Learning (Q3.5.) & Time Efficiency (Q3.1.)	0.461*	<.001	49
Contribution to Learning (Q3.5.) & Practical Use (Q3.2.)	0.683*	<.001	49
Contribution to Learning (Q3.5.) & Enjoyment of Drawing (Q3.6.)	0.628*	<.001	49
Contribution to Learning (Q3.5.) & Agility of Production (Q3.7.)	0.683*	<.001	49
Contribution to Learning (Q3.5.) & Advancement on Skills (Q3.8.)	0.512*	<.001	49
Contribution to Learning (Q3.5.) & Advancement on 3D thinking (Q3.9.)	0.375*	0.008	49
Contribution to Learning (Q3.5.) & Spot the Mistakes (Q3.10.)	0.500*	<.001	49
Contribution to Learning (Q3.5.) & Correct the Mistakes (Q3.11.)	0.643*	<.001	49
Analog Drawing Group			
Questions (as Keywords)	r_s	p	n
Contribution to Learning (Q3.5.) & Time Efficiency (Q3.1.)	0.287*	0.046	49
Contribution to Learning (Q3.5.) & Practical Use (Q3.2.)	0.363*	0.010	49
Contribution to Learning (Q3.5.) & Enjoyment of Drawing (Q3.6.)	0.398*	0.005	49
Contribution to Learning (Q3.5.) & Agility of Production (Q3.7.)	0.360*	0.011	49
Contribution to Learning (Q3.5.) & Advancement on 3D thinking (Q3.9.)	0.365*	0.010	49
Contribution to Learning (Q3.5.) & Correct the Mistakes (Q3.11.)	0.310*	0.030	49
Contribution to Learning (Q3.5.) & Ease of Archive (Q3.12.)	0.343*	0.016	49
Contribution to Learning (Q3.5.) & Less Feedback (Q3.13.)	0.408*	0.004	49

Similarly, in ADG, contribution to learning was found to have a significant positive correlation with the keywords as time efficiency, practical use, agility of production, correction of mistakes, ease of archive, and need for less feedback. It was understood that as analog drawing tool provides time efficiency, practical use, the agility of production, quick correction of mistakes, ease of archive, and need for less feedback, the students' perceived contribution to the learning of the drawing tool increases. It can be interpreted that ADG students who enjoyed the analog drawing tool and perceived an advancement in their 3D thinking ability evaluated the contribution of the drawing tool to their learning more positively.

In addition to that, a correlation between tools section and work environment section was analyzed (Table 6). In CDG, it was found that the phrase 'The physical environment in which I worked negatively affected my competence in the drawing tool' (keyword: relation of drawing competency

and environment) has a negative correlation with advancement on 3D thinking ability ($r_s = -0.285$, $p = 0.047$, $n = 49$). Based on this, the students that are affected by the physical environment have difficulties in advancing on three-dimensional thinking ability even if the majority of the students in CDG (%81.6) did not agree with the negative effect of the physical environment on their competency of the drawing tool.

Table 6. Results of Spearman's rho (r_s) Correlation test for the dependency between questions in tools and work environment sections

Computer Drawing Group (Online Education)			
Questions (as Keywords)	r_s	p	n
Relation of Drawing Competency and Environment (Q4.1.) & Advancement on 3D thinking (Q3.9.)	-0.285*	0.047	49
Relation of Drawing Competency and Environment (Q4.1.) & Participation to the Class (Q4.2.)	0.317*	0.027	49
Analog Drawing Group (Face-to-face Education)			
Questions (as Keywords)	r_s	p	n
Relation of Drawing Competency and Environment (Q4.1.) & Advancement on 3D thinking (Q3.9.)	-0.388*	0.006	49

Likewise, a positive association was found in CDG between the relation of drawing competency and environment and participation to the class ($r_s = 0.317$, $p = 0.027$, $n = 49$). This result suggests that the students have a problem with the physical environment that affects their drawing competency, they tended to report lower participation in the class. The results of ADG showed that there is a negative correlation between the relation of drawing competency and environment and advancement on 3D thinking ability ($r_s = -0.388$, $p = 0.006$, $n = 49$). Similar to CDG, if students were not satisfied with the physical environment, they also tended to evaluate their advancement in 3D thinking ability less positively. Overall, it can be concluded that students' comfort and suitability of the physical work environment may be related to their perceived development of 3D understanding in the drawing course, regardless of whether the course was conducted online or face to face.

Differences between socio-demographic characteristics

The questionnaire includes the socio-demographic variables section that provides information about the characteristics of the sample group. The number of enrollments in the Technical Drawing course was analyzed to reveal the differences in perception regarding the drawing tools.

According to the results of the Mann-Whitney U test, there are statistically significant relationships between the questions. The phrase 'It took me a while to adapt to the equipment of the drawing tool' was evaluated differently ($p=0.036$, $U= 782$, $z=-2.102$, $r= -0.21$). Most of the students that were enrolled in the technical drawing course for the first time (49.3%) agreed with the phrase whilst the students who took the course more than once (48.4%) disagreed. Secondly, first-time

enrolled students (50.7%) assessed the phrase ‘I need a specific working environment in this drawing tool’ affirmatively whilst students that took the technical drawing course more than once (80.6%) evaluated disapprovingly ($p=0.006$, $U=725$, $z=-2.749$, $r=-0.27$). Hence, they expressed familiarity with the drawing tools and working environment when compared to the first-time enrolled students. It was important to see that although they need to take the course again, it cannot be said that these students did not gain any of the course learning outcomes in their first enrollment to the course. Even if it looks like they succeeded in the course in one semester, learning is an ongoing process that includes cumulative information from the previous semesters.

Limitations of the research project

The scientific research project, which was focused on a hybrid teaching model of Technical Drawing course under the conditions of pandemic, was hurriedly structured because of giving urgent response to pandemic. The fundamental limitation of the research project is to structure the hybrid teaching model only on drawing tool, -mechanical hybridization on learning; therefore, the evaluation of learning outcomes mostly based on the drawing tool rather than course content. Hybridization on learning of the Technical Drawing Course in the research project was essentially a juxtaposition of conventional course content of Technical Drawing with computer-based drawing tool on digital work environment. Although this juxtaposition gains a hybrid learning capacity to the research project, it is not a radical learning transformation in digital turn. For the future researches, not only hybridization of drawing tool, but also the digitalization of course content will be tried. The scope of the future researches could be extended to how the digitalization in architectural drawing/visualization will be taught and learned.

CONCLUSION

The aim of the research project, which is designed for remote and online learning during Covid-19, has been determined as overcoming the problems to be experienced in teaching and learning the course Technical Drawing still taught by hand drawings. During the Covid-19 pandemic, the Technical Drawing course was digitally given to accomplish learning difficulties due to changes in the drawing environment experienced in transferring drawing medium from paper to screen. Parallel to course content, introductory AutoCAD lectures were given to students. With the help of the AutoCAD lectures, students directly produce their drawings in the digital environment; therefore, the paper work that restricted the students in remote and online learning was surpassed. The students in the remote and online learning process took the course digitally, which means that they were in a digital learning environment instead of an analog learning environment. This situation revealed a comparative study between the analog learning environment and digital learning environment of the technical drawing course; questionnaires were prepared to apply for both groups of students as ADG (Analog Drawing Group) and CDG (Computer Drawing Group). Fundamental inferences from the questionnaires could be listed as follows:

a) Course content: The content was conceived by both groups and no radical difference was found in the learning outcomes.

b) Course learning tool:

- In general, it is found that the computerized drawing tool is associated with time efficiency, practical use, mentally tiring, agility of production, the easy spot of mistakes, quick correction of mistakes, and ease of archive, while the analog drawing tool is time-consuming and lacks practical use. The results showed that analog drawing is associated with physically tiring, slow production, slow correcting of mistakes, and archiving difficulties according to the perception of students.
- If students who use the analog drawing method enjoy the drawing environment and develop three-dimensional thinking skills; they can comprehend the course content more easily and learn more quickly.

c) Work environment:

- It is found that the students who draw by computer can produce without the need for any physical medium. The fact that production through the computer is independent of the environment has revealed the need for a more flexible working environment.
- If students feel comfortable in the physical environment they work in, whether they have taken online or face-to-face education, their three-dimensional comprehension ability increases.

d) Socio-demographic differences: It is found that there is a cognitive difference in the perception of course conduction between the students that enrolled in the technical drawing course for the first time and the repeat students. It is observed that the learning process is an ongoing process with the accumulation from the previous semesters.

Parallel to these inferences, it is possible to conclude the article via three significant results. The first one is related to capturing standardization. In notational drawings even if it is drawn by hand or by computer, the main aim is to compose a norm and rule-based standardized drawing. Because of pursuing a norm-laden drawing, the technical drawing course's main scope is teaching norms and rules of drawing to obtain perfectness. Although it seems the course content (of Technical Drawing) is independent of the tool or the medium, notational drawings are depended to tools or mediums, in terms of teaching models or the drawing methods. The objective of the technical drawing course is to produce notational/definitive drawings, so much so that, it is obvious that giving the course content via analog method or digital method is significant in the context of obtaining standardized drawings.

The second important result is that if the matter is the communication via the help of the drawing, the tool becomes significant. The exchange of the “shared mental model” (Goldschmidt, 2017, 94), which was a supplementary item in the learning process, was realized through visual representations and images called “sketches”. In this context, the sketch as being an interpretive and indirect visual communication method is a thinking model. In order to provide drawing while thinking, the drawing tool should be used in an advanced way. At this point, it is possible to claim that drawing by hand could be more effective than drawing by computer in the thinking process of the designer, in terms of reflexivity of the hand to speedy thinking.

The third concrete result could be formed like that technical drawing could be seen as a “confirmation medium”, which tests the notions such as scale and proportion for the rule-based production. Technical drawing works as an intermediary platform between thoughts/ideas and the real. This qualification of the technical drawing makes it dissociated from the sketches. Thus, it is possible to claim that producing notational drawings by digital methods is easier and more effective way.

To conclude, it is possible to infer that the research project, which was implemented to teach technical drawing course during Covid-19 pandemic, revealed the results that can be summarized via three concepts: as capturing the standardization, the act of communication, and functioning as a confirmation medium. With the help of the development and implementation of the research project, challenges posed by the Covid-19 pandemic were addressed, and the project contributed to the digitalization process of the curriculum. After covid-19 pandemic, the Technical Drawing course in the curriculum has begun to be taught by a hybrid method. While developed in response to a specific context, the proposed hybrid teaching approach may also serve as a reference framework for courses and curriculums facing digital transformation challenges in future.

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