

# EMPLOYING VARIOUS 2D VISUAL APPEARANCES OF 3D OBJECTS TO EXPLORE THE UNDERSTANDING DIFFERENCES OF ORTHOGRAPHIC VIEWS IN GRAPHICAL EDUCATION

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## Abstract

This research presents experiment results as an educational reference for instructors to assist students to obtain an improvement appearance in learning the orthographic views. A visual experiment was designed to examine the comprehensive differences among four patterns of appearances of object features; the goal was to search the most adequate demonstration of 2D objects in the learning process. This empirical study provided one hundred and twenty-eight Taiwanese sophomores with four types of 3D visualization described by 2D static depictions, which include wireframe, texture, grayscale, and color, to meet five surface styles in orthographic views. The responses to views test and interviews illustrated that the applications of grayscale version occurred to be the worst perception in the four versions. In orthographic views test, the versions of wireframe and color both have better visual comprehension of objects; but when time and cost is considered in creating 2D objects, the wireframe version becomes a better and convenient choice.

## Introduction

Owing to the rapid growth of technology in 3D computer aided graphics, many kinds of software can not only build 3D solid models but directly transfer them into other drawing styles such as orthographic, isometric, and perspective views in 2D graphical environments. In addition, a variety of demonstration patterns can be created to

address the users' needs. They include wireframe, texture, grayscale, color, and so on. Most of them are usually widely used for graphical display of the object's 3D form. These ways of representation have also given rise to a new expression in the area of graphical learning. Todd's research [1] indicated that qualitative aspects of 3D structure (e.g. the arrangements of conspicuous image features, which are like occlusion profiles or edges of high curvature) would affect the perceptual representation of 3D form. Therefore, instructors can employ various objects' surface appearances to conduct the perceptions of orthographical views as a method for understanding the multi-views.

In previous research [2], the authors have also conducted an empirical study regarding how applying 2D static depictions and 3D animations can affect the learning of orthographic views. Aside from the 2D depictions of 2DR (2D static with rotating objects) or 2DT (2D static with transforming objects), other visualizations of 3D forms in 2D depictions may also affect the perceptions of object images in the orthographic views learning process. As a result, to explore the possible effects of other display styles in the orthographic views learning, four types of 3D visualizations have been designed to evaluate the learners' comprehensive ability of orthographic views. Research regarding some of the cues in perception of objects' performance has been concerned with, and investigated, these cues include color, texturing, binocular disparity, shadows, and so on [3, 4, 5,

6]. All of these cues were meticulously classified and defined by various functions. Furthermore, it is an obvious discrimination for human observers to feel a variety of perceptions by using them. Based on the approach of research, it is concluded that several criteria were used to evaluate the effectiveness among the themes of studies (e.g., depth (third dimension), distortion, discontinuity of textures, deforming cast shadows, DAT SR test, cognitive dimension, etc.). Taking into account these research strategies, our research has designed four different visual patterns of 2D depictions of 3D forms to examine the understanding of orthographical views. The study would also like to offer a display strategy to make learning and teaching more effective in the graphical courses. In order to avoid affecting the original attributes of test items, apart from the texture pattern, there is no luminance and shadow on the other three patterns in the views ability test. All objects of four patterns were drawn by the authors using the Package of 3D software. To decrease the complexity of visual expression,

there are only self shadows [7] on the objects described by the pattern of texture. Cast shadows were all ignored.

The rest of the study is constructed as follows. The related theoretical foundations are indicated in the next section. The methodology details are described in the following section, which contains experimental participants, material, analysis, and procedure illustrations. We then show the results of the empirical study and statistical analysis. Discussions are located in the next section. Finally, the conclusions and further studies are described.

### **Related Theoretical Foundation**

#### *Visual display of 3D shape*

There are several varied aspects of optical performance that are provided in many fields regarding 2D pictorial drawings. Four of these properties are introduced as follows (see Figure 1):

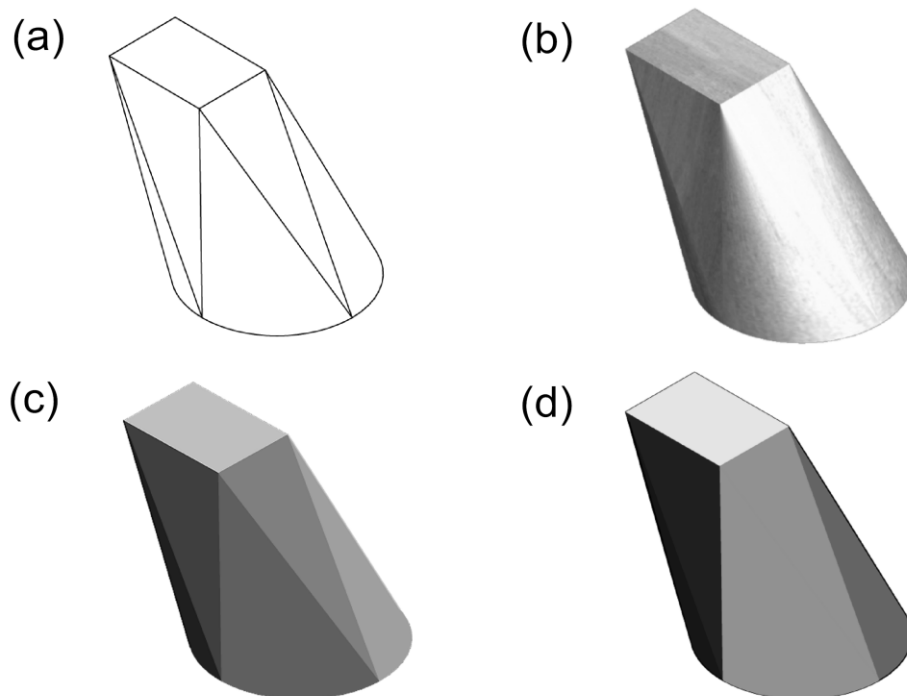


Figure 1: Four styles of display (a) wireframe (b) texture (c) grayscale (d) color.

- **Wireframe:** Line drawings, depicted by the contour of an object, usually contain the faces, edges, and vertices of objects. It is a very simple description method with no additional attributes, besides the occlusion contours, the attributes include shading, the different gradients of optical texture from mapping material patterns, color on the object surface. This style of display is easy to draw, and low cost. It is worth noting that when objects are depicted by wireframe, one must avoid the increase of the objects' complexity. The authors can review from the undesirable result of Kjelldahl & Prime's research [8] where too many lines were drawn on the object so that it became very similar to the other rendering object. A natural sketch [9] is employed in this research, due to the reason that it does not possess any hidden lines on the contours of the object, thus, it decreases the complexity of the object surfaces.

- **Texture:** When we want to describe images, texture is an important visual attribute. Texture is considered as the properties held and conceptions received by the outer surface of objects through optical image [10]. The texture perception of 3D shape is gained by a smooth curved object covered with a haphazard model of circular polka dots. By means of perspective expression, the optical projections of polka dots have produced different sizes and shapes along their relative position to the viewpoint of the observer [11]. The understanding morphology of the 3D surface belongs to the model of systematic changes that are considered as the gradients. In this study, a texture mapping is like an organizational changing model, which would be mapped by the test objects to increase their 3D dimensional quality. There are lots of properties in texture appearance, e.g., single or multi-scale, regular or irregular, symmetric or asymmetric [12]. According to Velisavljevic & Elder's research, the multi-scale, symmetric, random 'tartan' texture would produce the most precise attitude judgments. On the basis of this research, as well as a number of usages for making wooden pattern in the engineering

field, this study applies the wooden texture to the test objects.

According to the projecting directions of spotlight or point light source onto the objects, common illumination patterns are classified as parallel, divergent, convergent, ambient/diffuse, and hemispherical diffuse [13]. Different conditions of lamination would enable the object to produce a variety of 3D surface perceptions. Earlier researches indicated that observers perceive different aspects from the forms of luminance variation due to the gloss change in surface reflectance [14, 15].

- **Grayscale:** There is no apparent color on a grayscale image, which is defined to possess a number of different shades of gray from black to white. Black is the darkest part of the shade, whereas white is the lightest part of the shade. Generally speaking, the image on a computer display is described by the brightness values of the three main colors, which are red, green, and blue, used for transmitted light. These values are each ranged from 0 to 255. Every pixel of a grayscale image has an equal brightness value (black is presented by  $R = G = B = 0$ , and white is presented by  $R = G = B = 255$ ). Aside from using the RGB color mode to define grayscale, hue, saturation, and lightness are also often used. The hue and saturation value of each pixel in a grayscale image is 0; the grayscale image then can be changed by the variation of lightness of a pixel. Grayscale image has also been widely applied in many fields, especially in diagnostic technology of medicine [16, 17].

- **Color:** Color science [18] is widely applied in various fields, such as food, clothes, architecture, transportation, arts, and entertainment, and so on. A few researchers explored the uses of color regarding object localization, object search, and spatial facilitation [19, 20, 21]. These studies demonstrate that color indeed played an important role in object visualization, including querying an object's shape, detecting line targets, and searching the object with color to reach the histogram. In general, color models are classified in two categories which are device-dependent and device-independent [22];

the former include RGB, CMY, HSV, and HSL color models, while the latter are CIE XYZ derived into CIELUV and CIELAB color models. The RGB model is mainly applied by the Application Interfaces (APIs) in computer systems, because monitors create color images by transmitting RGB light into observers [23].

In the RGB color model, each color is obtained by the combination of the three primaries, which are red, green, and blue. When all primaries are mixed with equal intensity, the color white will be produced, therefore, it is identified as the additive model. On the other hand, the CMY color model is defined as the subtractive model. HSV (hue, saturation, and value), HSL (hue, saturation, and lightness) are other additional color models. With the usage of 3D software in computer aided drawing, 3D graphics depicted by 2D shapes would be colored with different values of lightness to increase the three-dimensional quality of objects. In this paper, the authors apply the HSL color model to render isometric drawings with various colors. As for the categories of color names [24, 25, 26], the four categories, divided by Rich, were employed; the categories included basic, qualified, qualified fancy, and fancy-color. After suggesting Sleight & Prinz's classification, we then consulted Simpson & Tarrant's development of the seven category color names which removed some color names in the basic category. In this research, the color names are adapted from the basic category, which are white, black, grey, red, yellow, green, blue, orange, purple, brown, and pink. Therefore, all the objects in views test are colored by the color names of this category.

### ***Orthographic views and isometric drawings***

Objects can be depicted by the orthographic views to express their features, including surface types, sizes, shapes, and so on. Orthographic views are obtained by the parallel projections in which the lines of sight are assumed to be parallel to each other and perpendicular to the object from the observers

[27]. An isometric drawing is defined to place an object in a specific angle so that its principal edges or axes make equal angles with the project plane. As a consequence, it can simultaneously show the shapes of the object from three directions (xy, yz, and zx planes). Sometimes when the objects are constructed by complicated structure, due to the lack of complete shapes and sufficient sizes, it is necessary to add one or more isometric drawings to be described from other points of view. When there is an isometric drawing of an object that is to be described with orthographic views, students would usually begin drawing them from vertices to edges and faces to finally complete the projection views.

Several investigations regarding reconstruction of 3D models from 2D orthographic views are noted. The approaches and methods were conducted by a series of feature commands (e.g., extrusion, revolution, and sweep, etc) and various strategies [28, 29, 30]. Based on the results of these studies, it is obvious that there would be close correlation between the orthographic views and constructions of a 3D object. Only when the correct orthographic views were first provided, could the 3D object be precisely reconstructed. Conversely, if students misunderstand the features of an object, including shapes, sizes, and so on, they would certainly make an incorrect description regarding the orthographic views of the object. In short, the higher the clarity of the 3D objects visual appearances can be displayed, the more the orthographic views will be precisely described, and vice versa. In our previous study [2], the experimental results also proved the same conclusion. Students in 3DR and 3DT groups had better achievement than other two groups (2DT & 2DR) in the orthographic views tests, because the former testing objects had a clearer visual appearance, especially when objects were constructed by the complicated surface types.

## Methodology

### Participants

One hundred and twenty-eight sophomores (80 male, 48 female, age  $M = 21$ ), who were from four classes of two universities in northern Taiwan were committed to the empirical study. In order to ensure every participant acquires the basic abilities of orthographic views, all of them have to finish a one year course of graphics and obtain the credit before participating in the empirical study. In addition, these four classes were taught by the same graphic instructor throughout the course.

All the three parts of the view test in the empirical study are fully designed with 2D static performance including four styles of depictions. All participants were randomly divided into four groups. According to Gay & Airasia' theory [31], every group ( $n = 32$  participants per condition) was assigned to one of four conditions, which were expressed by wireframe, texture, grayscale, and color. Each group had an average participant of 12 females and 20 males.

## Materials

### Displays of the views ability test

There are four display versions in the orthographic views ability test. Four versions of test objects are separately performed by wireframe, texture, grayscale, and color (see Figure 2). In the orthographic views test, each item includes two isometric drawings, which show two directions of rotating angle (90 degree on z axis). According to the test objects' front view, the directions of two isometric drawings of objects are specially selected to correspond with the need of observers. Aside from the version of texture, light and shade are all ignored from the rest of the versions to avoid a negative effect toward their attributes. The questions for each version of the views test includes answers regarding various views which are evenly distributed in the questions, covering the front, right, left, and top views. In the wireframe version, all test objects are drawn by natural sketch. This study applies the wooden texture to map the test objects for the texture version; there are also two sources of parallel light located at the upper right & left frontal sides the test objects. Moreover, self


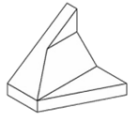




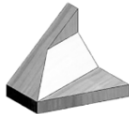
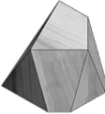

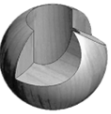










Kinds of Surfaces \ Styles of Display	Kinds of Surfaces				
	Normal Surfaces	Inclined Surfaces	Oblique Surfaces	Cylindrical Surfaces	Double-curved Surfaces
Wireframe					
Texture					
Grayscale					
Color					

Figure 2: Four styles of display (degree of difficulty: hard).

shadows are created on the test objects to increase luminance. In the grayscale version, a wide range of scales of lightness are modulated to highlight the intersections of surfaces. Test objects in the color version are colored by selecting from the basic color category, and adjacent surfaces were to match the harmony color principle as much as possible. To visualize the features of adjacent surfaces, a number of scales of color lightness also are employed. The experiment was committed on a PC monitor so that every computer would be checked to identify the color steadiness prior to processing the experiment.

### Contents of the orthographic views test

In the orthographic view test, each test version contains a total of twenty questions, fifteen geometric questions regarding structural objects and five daily commodities questions (see Figure 3). According to the previous authors' work [2], test objects were divided into five kinds of surface with three degrees of difficulty (easy, medium, and hard). The five surfaces include normal surfaces, inclined surfaces, oblique surfaces, cylinders, and

double-curved surfaces, respectively. Each question always has a set of orthographic views and two isometric views of objects to ask the participants to choose the correct view from the four alternatives according to the assigned front view (see Figure 4). After watching the display of each version on a PC screen, the participants of each group had to fill answers in the answer sheet (see Figure 5); the answer sheet was provided with two parts for the orthographic views. The maximum score in the first part of the orthographic views test was 15, the second part was 5 (each correct answer scored 1, and each wrong answer scored 0).

### Analysis

At the end of the experiment, all four display styles would be shown by the participants of each group, and each is asked to choose their favorite versions of display. Furthermore, there was one interview conducted to capture the participants' perceptions and impressions concerning the different performances of objects. A variety of data sources would be collected by synthesizing all participants' scores of views test and interviews. Two




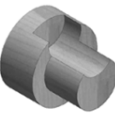

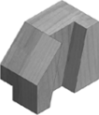


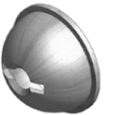



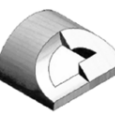
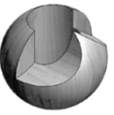



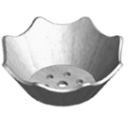

Kinds of Surfaces Styles of Display	Normal Surfaces	Inclined Surfaces	Oblique Surfaces	Cylindrical Surfaces	Double-curved Surfaces
	Easy				
Medium					
Hard					
Five daily commodities					

Figure 3: Fifteen items and five daily commodities in the views ability test.

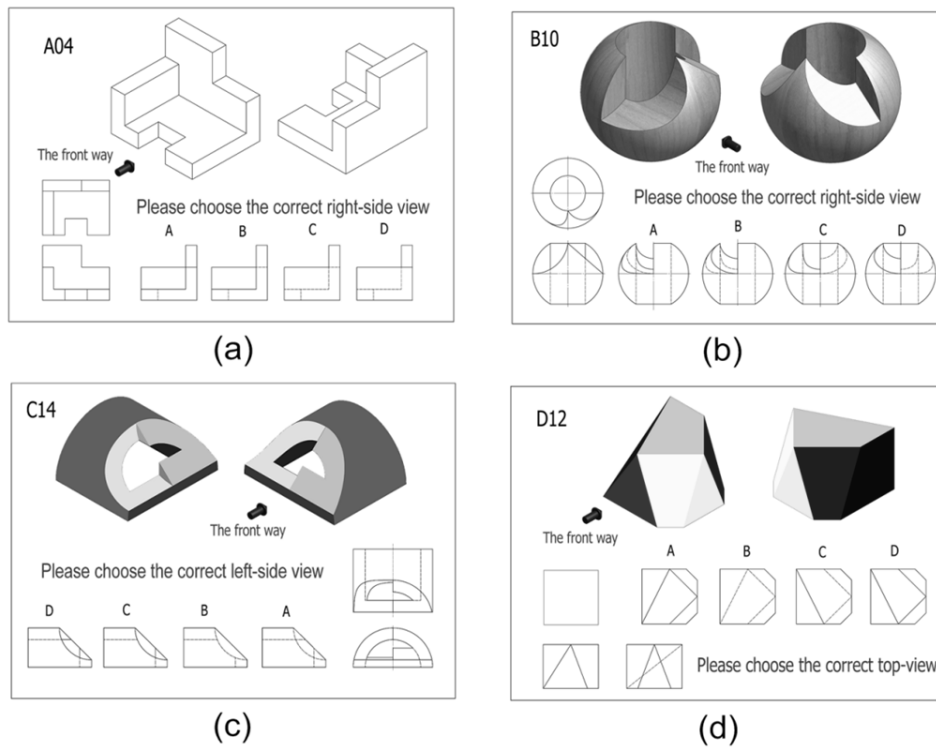


Figure 4: Four examples of orthographical views in the views ability test  
 (a) wireframe (b) texture (c) grayscale (d) color.

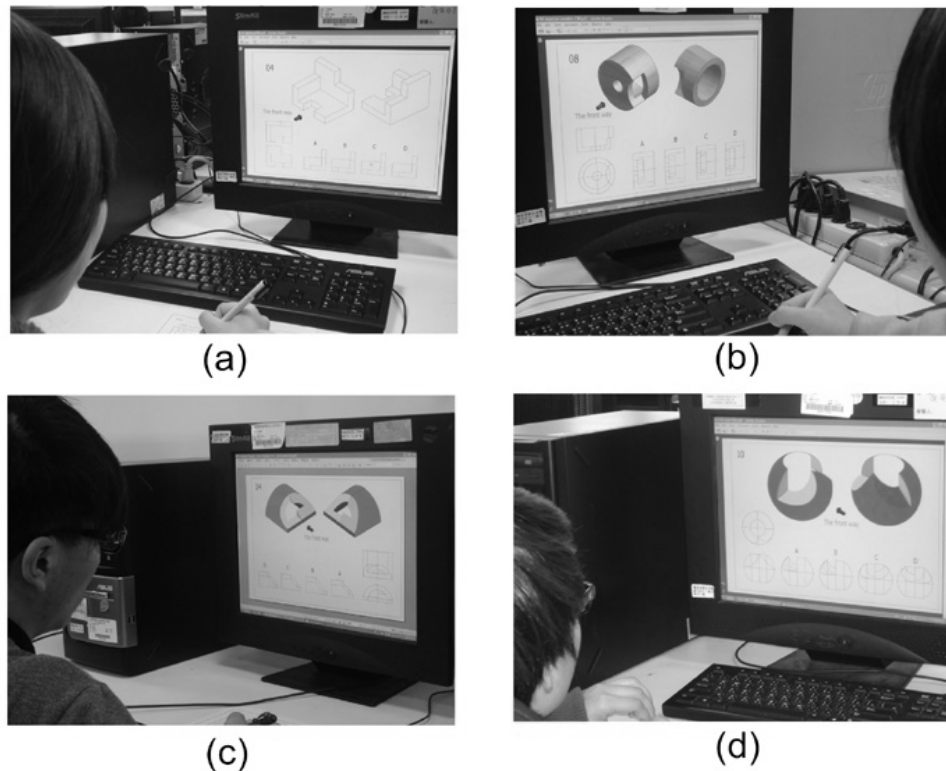


Figure 5: Actual performance of four types of display  
 (a) wireframe (b) texture (c) grayscale (d) color.

analytic methods including validity and reliability were applied in this test. The analysis of validity consists of two parts: content validity and criteria validity. Content validity is evaluated from experts' opinions. Eight members who were instructors of graphic courses and scholars of industrial design were committed in the expert group. These experts expressed their opinions to evaluate if the views test were correlated to the related fields [31] and then discussed and modified the final contents of the survey. Criteria validity was inspected by the correlation coefficient between the scores of the graphic course (regarding orthographic views) and the scores of the views test of 30 sophomores from one of the two Universities which participated in this research. In short, there was a significant positive correlation between the two scores (Pearson Correlation is 0.812\*\*).

The study then employed a retest of reliability to inspect the stability of the views test. For the first step to process the retest reliability, thirty participants were selected from the other university to evaluate this test. One month later, there was a retest to be taken by the same participants. The scores of the two tests were evaluated through a correlation coefficient; as a result, a significant positive correlation appeared (Pearson Correlation is 0.664\*\*). The total scores of the views test for every participant were calculated by counting the numbers of the correct alternates, the data

analysis in this study included comparison of the four displays of object features. On the other hand, degrees of difficulty and gender were also conducted.

### Procedure

All participants were randomly divided into four groups to operate in the empirical study: each group was randomly assigned to conduct one of the four versions of displays. Each participant committed to the experiment with an individual computer and wrote down the answer on the answer sheet after watching each question on-screen. In general, the time period for answering each question was one minute; the questions were randomly set and presented. The instructor operated a region connected network to control the progress of the empirical study, and the entire survey lasted approximately twenty minutes.

### Results

An analysis of variance (ANOVA), *t*-test, and Chi-square were performed in this study. The statistical results of the orthographic views test are presented.

Table 1 is the descriptive statistic and analysis of variance for comprehension regarding all five surfaces within 20 objects (the first and second parts) in four versions of display. Whichever test was conducted in the first part

Table 1: Descriptive Statistics & Analysis of Variance for comprehension regarding all five surfaces of twenty objects (the first and second part) in the four versions of display.

Variable	Wireframe		Texture		Grayscale		Color		ANOVA	
	M	SD	M	SD	M	SD	M	SD	F(3,12)	<i>p</i>
Orthographic views test (15 objects)	12.78	2.35	12.13	2.32	10.91	2.49	12.88	1.64	5.310**	0.002
Orthographic views test (5 products)	3.75	1.10	3.88	0.97	3.78	0.83	4.16	0.76	1.265	0.289

Note, N = 128 for all measures. n = 20 for each version of display.

\*\*  $p < 0.01$



or second part, the color version always received a better orthographic views comprehension of the objects features (wireframe:  $M_1 = 12.78$ ,  $M_2 = 3.75$ , texture:  $M_1 = 12.13$ ,  $M_2 = 3.88$ , grayscale:  $M_1 = 10.91$ ,  $M_2 = 3.78$ , color:  $M_1 = 12.88$ ,  $M_2 = 4.16$ ). In the first views test, we found significant difference concerning the displays of color, wireframe, and grayscale ( $F = 5.310$ ,  $P = 0.002$ ). According to the Scheffe's comparison, the wireframe and color versions were superior to grayscale, but there was no significant difference within the five products. The reason might be because most of the five products were classified as easy in the degree of difficulty.

Moreover, we alternately analyze the comprehension effectiveness for each of the five surfaces with the four versions in the first part; the statistical results are presented in Table 2. The three outcomes are as below:

1. When the surfaces of objects are normal surfaces, oblique, and cylindrical surfaces, there was no significant difference to be found

within the four versions of display. Even so, the mean of the grayscale version was always the lowest of the four versions (grayscale:  $M_{\text{normal surface}} = 2.66$ ,  $M_{\text{oblique surface}} = 1.69$ ,  $M_{\text{cylindrical surface}} = 2.50$ ).

2. When the objects are constructed by inclined surfaces, there was a significant difference concerning the displays of color, wireframe, and grayscale ( $F = 8.26$ ,  $P = 0.00$ ). According to the Scheffe's comparison, students who were assigned with the wireframe and color versions have a better perception than the grayscale version (wireframe:  $M = 2.81$ , color:  $M = 2.81$ , grayscale:  $M = 2.13$ ).

3. When the objects are double-curved surfaces, the statistical results revealed that there was a significant difference regarding the displays of color and grayscale ( $F = 2.94$ ,  $P = 0.03$ ). Based on the Scheffe's comparison, students who were assigned with the color version had a better perception than the grayscale version (color:  $M = 2.47$ , grayscale:  $M = 1.9$ ).

Table 2: Descriptive statistics of comprehension regarding four types of displays in the five surfaces (the first part) respectively.

Variable	Wireframe		Texture		Grayscale		Color		ANOVA	
	M	SD	M	SD	M	SD	M	SD	F(3,124)	p
Normal Surfaces (3 objects)	2.75	0.44	2.81	0.39	2.66	0.60	2.91	0.29	1.77	0.15
Inclined Surfaces (3 objects)	2.81	0.47	2.50	0.67	2.13	0.90	2.81	0.39	8.26***	0.00
Oblique Surfaces (3 objects)	2.22	0.79	1.81	0.96	1.69	0.93	1.91	0.77	2.17	0.09
Cylindrical Surfaces (3 objects)	2.59	0.75	2.63	0.55	2.50	0.67	2.78	0.55	1.07	0.36
Double-Curved Surfaces (3 objects)	2.31	0.86	2.38	0.75	1.91	0.89	2.47	0.76	2.94*	0.03

Note, N = 128 for all measures. n = 15 for each version of display.

\* $p < 0.05$ , \*\*\* $p < 0.001$ .

If the surfaces of objects, including five types of surface, are constructed by the hard degree, which we also found statistically significant difference regarding color, wireframe, and grayscale ( $F = 5.38, P = 0.002$ ). Based on Scheffe's comparison, students who conducted the wireframe and color versions have a better perception than the grayscale version (wireframe:  $M = 4.31$ , color:  $M = 4.16$ , grayscale:  $M = 3.34$ ). On the other hand, the easy degree was not significant ( $F = 0.83, P = 0.48$ ) (see Table 3).

Gender factor, as previous work is described, does not affect the comprehensive effectiveness of object features. To reassure this conclusion, we again explore the possible relationship

among gender; the authors can see from Table 4, the statistic results found no significant difference between male and female ( $M_{\text{female}} = 11.79, M_{\text{male}} = 12.40, t(126) = 1.431$ ). In other words, the factor of gender did not significantly affect the comprehensive results of the test.

In the last question of the views test, all participants were asked to select which version of display was the optimal option. Texture version (32.1%) was the most popular choice selected by the students in the orthographic views test. Through the statistic analysis of Chi-square, the significant difference existed in the tests (views test:  $\chi^2 = 14.969, p < 0.01$ ). Moreover, the instructor also expressed his observations and reactions to the experiment.

Table 3: Descriptive Statistics & Analysis of Variance for comprehension with different difficulty regarding all five surfaces (the first part) in the four versions of display.

Variable	Degree of difficulty	Wireframe		Texture		Grayscale		Color		ANOVA	
		M	SD	M	SD	M	SD	M	SD	F(3,124)	p
Orthographic views test (5objects)	Easy	4.34	0.90	4.41	0.91	4.28	0.85	4.59	0.66	0.83	0.48
Orthographic views test (5objects)	Hard	4.31	0.93	3.84	1.16	3.34	1.18	4.16	0.84	5.38**	0.002

Note, N = 128 for all measures. n = 15 for each version of display.

\*\*  $p < 0.01$ .

Table 4: Students' views ability test scores toward all types of surface of object by two groups of different sex.

Variable	Sex group	M	SD	t	Difference's comparison
Views test of all types of surface (15 objects)	female	11.79	2.269	1.431	No significance
	male	12.40	2.363		

Note, N = 128 for all measures. Male = 80, female = 48.

## Discussion

In general, the grayscale version had been proved to be the worst perception of the orthographic tests. It was obviously identified when the objects were constructed by the complicated shapes or surfaces, like oblique and doubled curved surfaces in the orthographic views test. Indeed, it appears that there was no significant difference among the versions of wireframe, texture, and color in the test. If the instructors take account of the convenience and cost in creating the objects, the version of wireframe would seem to be a better choice compared to the others. We also find that the texture version was the most popular choice chosen by the students during the orthographic views test. A number of students thought that the objects were represented with characteristics of luminance and gloss; as a result, they could express the objects with a more realistic appearance. Even so, the texture version did not get the best perception with respect to the objects features. The authors believes that the main reason for this occurrence is because the orthographic views needed to rotate the objects, and imagine the object's projected views; therefore, although they possess 3D dimensional quality, it is difficult to completely understand the object's feature; it is only to improve the visual effects of a 2D object.

As concluded in the previous research [2], 3D animations, due to its characteristics of rotating and transformation, is proven to have good effectiveness in comprehending the object features. The reactions and perceptions from the interviews with participants relates to the outcome of the research. First, few students thought that the wireframe version was so concise and clear that it was easy to understand the objects. Second, many students said that the objects depicted by black and white appeared too similar to distinguish the object features in the grayscale version. Finally, some students considered that a range of colors on the surfaces of objects would cause confusion in

appearance due to lack of color harmony [33], yet several also claimed it was a benefit from distinguishing varied surfaces of objects.

During the empirical study, the instructor also found some problems and expressed his observations as follows. First, in the orthographic views test, the hidden lines could be adequately added on the objects, the width adjustment of the contours lines can also changed the luminance of objects, because this method of depictions only affect the object's outline, not the attributes of surfaces. Second, in the color version, to avoid the confusion of multiple colors on an object, it would be suggested that the object adapts to only one color with different lightness to distinguish the different surface features of the object. Third, the misunderstanding usually happened because there was only one arrow indicating the front view with two isometric views of the object in the orthographic views test, and an arrow of another direction should be added for assistance.

## Conclusions

This research mainly explores the effects in regards to teaching and learning the orthographic views by focusing on the 2D performance of objects which were depicted by four versions of objects surfaces expression. The results indicate that the comprehension of the object features is mainly correlated to the types of surface, degree of difficulty, and display of objects' appearance. This study synthesized the use of attributes (e.g., wireframe, texture, grayscale, and color) to design four kinds of surface performance for examining student's perception through the orthographic views test.

In conclusion, the result of the orthographic view test revealed that the color version was indeed comprehended as more effective than the grayscale version. When the objects constructed by simpler surface styles like normal, inclined, and cylindrical surfaces, the statistical outcome shows the wireframe version is a better and convenient choice,

especially, when the objects belonging to hard degree in the orthographic views test. Regardless of the degree of difficulty, the color version is the most suitable way to display these features of 2D objects. Moreover, this study also takes account the gender factor that may affect the empirical study, and the evaluation results show that there was no significant difference between male and female. In short, regardless of the participants' gender, the abilities to select the correct orthographic views are shown to be equal.

### ***Results of student feedback and suggestions***

The results of student feedback are described as followed.

- When the objects are constructed by simpler surface styles, like normal, inclined, and cylindrical surfaces, the wireframe version should be a better and convenient choice.
- Several students considered that the objects depicted by the grayscale are more difficult to distinguish their features.
- In order to avoid the confusion in appearance in the color version, complex colors on object surfaces are avoided. If necessary, different lightness of color would be employed.

Suggestions are provided in the following.

- In the teaching and learning of graphical courses, a computer is a very useful and convenient tool to demonstrate the drawings of study, because the instructors and students can arbitrarily manipulate the drawings as they desire, such as rotation, and zoom.
- When we used a computer to understand the features of objects, it is necessary and easy to add the hidden lines in the objects constructed by the complex surfaces, like

oblique and double-curved surfaces.

- If possible, let the students operate computers by themselves in the views ability test.
- When the drawings are expressed by computer, colors, arrows, and texts should be adequately added since it would help student to understand.

### ***Possible teaching and learning procedure***

On the basis of the results and findings of this empirical study, the authors elaborately provide the possible teaching and learning procedure for learning orthographic views. According to Bloom's taxonomy of educational objectives [34], categories were arranged from easy to complex in the cognitive domain [35]. Therefore, the authors applied this principle for offering learning procedure. In the teaching of orthographic views, the instructors should identify the sequence of teaching in relation to the surface styles of objects based on the degree of difficulty in surfaces projection and the results of statistical analysis (Table 2). Normal surface is suggested to be taught first, then the inclined surface is the next, finally the oblique surface. In the teaching of curve parts, cylindrical surface should be taught first, then double-curved surface. As for the display of visual appearances of objects, regardless of the surface style and degree of difficulty of objects, the wireframe style is always applied for object display; this is because the statistical analysis shown no significance within texture and color (see Tables 2 and 3). The wireframe style had the best display results, even when the objects are classified in the oblique style and hard degree. Additionally, it is more convenient and easier for students to draw them with pen or other tools.

Apart from the teaching procedure mentioned above, instructors should design a variety of training aids created by the 3D software to let students have more opportunity to operate these graphic models by themselves. If so, the visual

performance of object displays will become more prompt and flexible to satisfy individual needs.

### ***Further studies and limitations***

Further studies should include how to apply the function of animation to the orthographic drawing: and to compare the learning effectiveness between static depictions and 3D animations by means of colors, different texture, and interactive learning via empirical study.

There are some limitations in this study. First, the progress of empirical study is only controlled by the instructor. Hence, it does not correspond to the participants' needs. Especially when the students want to enlarge or move the drawings, they can not freely manipulate the computer by themselves. Surely, if the students can conduct the views tests by themselves, this procedure will be more beneficial to interactive learning with students. Second, the objects of tests are depicted by 2D state, so the directions cannot be rotated or changed to completely observe the actual 3D shapes.

To sum up, the results and discussions derived from the research findings show that computer software technologies and good display styles are able to promote teaching and learning developments regarding orthographic views in graphical courses. Above all, it demonstrates that the additive attributes will facilitate the capability in displaying object features and inspire the potential study for the relative issues of graphics. The results of this study could provide further learning and instructing guidelines for students and teachers.

### **References**

1. J. T. Todd, "The visual perception of 3D shape. *TRENDS in Cognitive Sciences*," 8(3), 115-121. 2004.
2. C. F. Wu, and M. C. Chiang, "Effectiveness of applying 2D static depictions and 3D animations to orthographic views learning in graphical course," *Computer & Education*, 63(2013), 28-42.
3. P. Cavanagh, "Reconstructing the third dimension: interactions between color, text, motion, binocular disparity, and shape." *Computer Vision, Graphics and Image Processing*, 37(2), 171-195. 1987.
4. J. M. Dischler, and D. Ghazanfarpour, "A survey of 3D texturing," *Computers & Graphics*, 25(1), 135-151. 2001.
5. J. F. Norman, Y. L. Lee, F. Phillips, H. Norman, L. R. Jennings, and T. R. McBride, "The perception of 3-D shape from shadows cast onto curved surfaces," *Acta Psychologica*, 131(1), 1-11. 2009.
6. P. Skorupski, and L. Chittka, "Is colour cognitive?" *Optic & Laser Technology*, 43(2), 251-260. 2011.
7. S. Elena, C. Andrea, and E. Touradj, "Cast shadow segmentation using invariant color features," *Computer Vision and Image Understanding*, 95(2), 238-259. 2004.
8. L. Kjelldahl, and M. Prime, "A study on how depth perception is affected by different presentation methods of 3D objects on a 2D display," *Computer & Graphics*, 19(2), 199-202. 1995.
9. S. Kyratzi, and N. Sapidis, "Extracting a polyhedron from a single-view sketch: Topological construction of a wireframe sketch with minimal hidden elements," *Computers & Graphics*, 33(3), 270-279. 2009.

10. W. Groissboeck, E. Lughofer, and S. Thumfart, "Associating visual textures with human perceptions using genetic algorithms," *Information Sciences*, 180(11), 2065-2084. 2010.
11. L. Thaler, J. T. Todd, and T. M. H. Dijkstra, "The effects of phase on the perception of 3D shape from texture: Psychophysics and modeling," *Vision Research*, 47(3), 411-427. 2007.
12. L. Velisavljevic, and J. H. Elder, "Texture properties affecting the accuracy of surface attitude judgments," *Vision Research*, 46(14), 2166-2191. 2006.
13. H. T. Nefs, "On the visual appearance of objects," *Product Experience*, 11-39. 2008.
14. R. W. Fleming, R. O. Dror, and E. H. Adelson, "Real-world illumination and the perception of surface reflectance," *Journal of Vision* 3(5), 347-368. 2003.
15. F. B. Leloup, M. R. Pointer, P. Dutre, and P. Hanselaer, "Luminance-bases specular gloss characterization," *Optical Society of America*, 28(6), 1322-1330. 2011.
16. J. P. M. Sedelaar, J. G. H. Van Roermund, G. L. J. H. Van Leenders, C. A. Hulsbergen-Van De Kaa, H. Wijkstra, J. J. M. C. H. De La Rosette, "Three-dimensional grayscale ultrasound: Evaluation of prostate cancer compared with benign prostatic hyperplasia," *Adult Urology*, 57(5), 914-920. 2001.
17. A. Maehara, E. Cristea, G. S. Mintz, A. J. Lansky, O. Dressler, S. Biro, et al, "Definitions and methodology for the grayscale and radiofrequency intravascular ultrasound and coronary angiographic analyses," *Cardiovascular Imaging*, 5(3), 1-9. 2012.
18. M. R. Luo, "Applying colour science in colour design," *Optics & Laser Technology*, 38(4-6), 392-398. 2006.
19. Y. Zhong, and A. K. Jain, "Object localization using color, texture and shape," *Pattern Recognition*, 33(4), 671-684. 2000.
20. N. Wada, S. Kaneko, and T. Takeguchi, "Using color reach histogram for object search in colour and/or depth scene," *Pattern Recognition*, 39(5), 881-888. 2006.
21. B. Dresp, and S. Grossberg, "Spatial facilitation by color and luminance edges: boundary, surface, and attentional factors," *Vision Research*, 39(20), 3431-3443. 1999.
22. S. Silva, B. S. Santos, and J. Madeira, "Using color in visualization: A survey," *Computer & Graphics*, 35(2), 320-333. 2011.
23. Y. C. Hou, "Visual cryptography for color images," *Pattern Recognition*, 36(7), 1619-1629. 2003.
24. E. Rich, "Gender-related differences in colour vocabulary," *Language and Speech*, 20(4), 404-409. 1977.
25. C. C. Sleight, and P. M. Prinz, "Children's colour vocabulary," *Language and Speech*, 25(1), 75-79. 1982.
26. J. Simpson, and A. W. S. Tarrant, "Sex- and age-related differences in colour vocabulary," *Language and Speech*, 34(1), 57-62. 1991.
27. F. E. Giesecke, A. Mitchell, H. C. Spencer, I. L. Hill, R. O. Loving, J. T. Dygdon, and J. E. Novak, *Engineering*

*Graphics*, Macmillan, New York, N. Y. 1993.

28. A. Cicek, and M. Gulesin, "Reconstruction of 3D models from 2D orthographic views using solid extrusion and revolution," *Journal of Materials Processing Technology*, 152(3), 291-298. 2004.
29. H. Lee, and S. Han, "Reconstruction of 3D interacting solids of revolution from 2D orthographic views," *Computer Aided Design*, 37(13), 1388-1398. 2005.
30. L. Cayiroglu, "A new method for machining feature extracting of objects using 2D technical drawings," *Computer Aided Design*, 41(12), 1008-1019. 2009.
31. L. R. Gay, and P. Airasian, *Educational Research*. NJ: Prentice-Hall, Inc. 2000.
32. J. W. Creswell, *Planning, conducting, and evaluating quantitative and qualitative research. Educational research*. Upper Saddle River, NJ: Person Education Inc. 2002.
33. A. Wright, *The beginner's guide to colour psychology*. London: Kyle Cathie Limited. 1995.
34. B. S. Bloom, *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. New York: David McKay Co Inc. 1956.
35. D. R. Krathwohl, "A revision of Bloom's taxonomy: An overview," *Theory into Practice*, 41(4), 212-218. 2002.

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