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User Evaluation of a Virtual Colour Laboratory as a Tool for Demonstrating Colour Appearance

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Abstract: The aim with our research is to contribute to a better understanding of how colour research findings can be conveyed to a broader target audience, using digital media. This article presents a user study focusing on the popular science project the Virtual Colour Laboratory *(VCL). The VCL is an interactive webpage for presenting and demonstrating existing research results on spatial colour phenomena. It was initiated and carried out with the intention of spreading knowledge of colour appearance and colour perception to a wider target audience, from the viewpoint of practice based architectural colour research. The VCL enables the user to investigate actively how colours appear in different situations, and provides information on relevant literature and links for further studies. In a questionnaire study, carried out in 2014, two groups of users including architecture students and professionals within architecture, art and design evaluated the usability of the VCL with a combination of qualitative and quantitative methods. The predominant result showed that the VCL generally was highly appreciated. However, the results also show differences in how the two groups experienced the visual and written content of the stations in the VCL, as well as differences in how they experienced the VCL as a whole. This highlights the importance of adjusting levels of information depending on the target group, as well as presents advantages and difficulties of showing research on spatial colour appearance on the web using digital visualization as a medium for presentation.* Col Res Appl, 41, 611–625, 2016; Published Online 13 October 2015 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.22000

Key words: colour appearance; colour phenomena; colour research; visualization; user study; web-based learning tool; NCS

INTRODUCTION

How can colour phenomena be displayed and explained so that people will understand them correctly? It is a hard task, since colours always need to be experienced visually. Our other senses cannot convey what colours are, and words are not sufficient in themselves to explain them. The traditional way of mediating colour is through illustrated written material in physical shape, like books. Using digital media and the Internet in order to explain colours is starting to become increasingly common, allowing a great variety in ways to present the information. At numerous websites various kinds of colour phenomena are explained using different terminology and different methods. Blogs, managed by communities or individuals, are used for presenting, sharing and discussing colour appearance and colour phenomena, often in the contexts of design, fashion, crafts, etc.[1–4] Other websites have a complete, or partial, focus on academic or professional colour research.

Where colour research is concerned, a common type of website is that published by individual researchers, or research groups, about their own work. The aim of such sites is to convey their research to a larger audience. The material is most often presented with images and short explanatory texts;[5] with short interactive demonstrations;[6] or with short films.[7] General colour science is presented

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and demonstrated on the Internet for profitable or non-profitable purposes by companies or individuals. A wide spectrum of tutorials focused on basic colour education and colour science can be found displayed, for example, as web pages with static or interactive written and visual information;[8] as short films on e.g. YouTube;[9] or as downloads in the shape of e-books.[10] A popular subject on websites including colour science, published by researchers or other individuals with an interest in the field, is the description of colour and lightness phenomena by using the term *illusions*.[6,11–14] Here the perspective is that colour is an illusion. Typical, however extreme, phenomena related to contrast are visually displayed, often from a 2D-perspective. Adaptation plays a central role, and the visualization are central as means for the presentation. Other websites which include colour research are created by organizations, often at a national level, such as *The Colour Society of Australia*[15] and *Colour Research Society of Canada*.[16] Those sites aim to serve as platforms and communities for people from diverse areas of practice and academic disciplines connected to colour, and are often restricted in terms of requiring membership to access the content. Research here can, for example, be presented with links to conferences and conference proceedings. *Colourspot*[17] by *Swedish Colour Centre Foundation* provides short written information and links on some current Scandinavian colour research.

A common type of website is that published by consultants within e.g. brand identity, product design, packaging design, logos, and corporate image.[18,19] These sites present their own specific studies and projects within colour research, with the aim of promoting their own services. Other companies, for example paint or wallpaper manufacturers such as *Dulux* and *Alcro Becker*, present how a coloured material will appear in a room, with the aim of visualizing their products. A common method used on this kind of site is to choose a paint or wallpaper sample and see what it will look like when painted on the surfaces of a room in an interactive model[20] or in an image.[21] The question here is how well this method conveys the effects the coloured material will have on the total colour appearance of the room in terms of, for example, reflections, or if they just take the colour sample and transfer it to the walls of the room model.

We have so far been unable to find a web-based tool similar to the VCL, with the purpose of demonstrating colour research findings for educational purposes. When it comes to the evaluation of web-based learning tools similar to the VCL but focusing on other areas than colour research, user studies are so far few in number[22,23] which makes this study important.

AIM, SCOPE, AND LIMITATIONS

The aim with our research is to contribute to a better understanding of how colour research findings can be conveyed to a broader target audience, using digital media. In this article we discuss the challenges of presenting research results on spatial colour appearance on the web using digital visualization as a medium for presentation. A user study is presented, focusing on the popular science project *the Virtual Colour Laboratory* (VCL)*.[24–26] The VCL is an interactive webpage developed for presenting and demonstrating existing research results on spatial colour phenomena. It was initiated and carried out at the Department of Architecture at Chalmers University of Technology with the intention of contributing to a more widespread understanding of colour appearance† in the built environment, from the viewpoint of practice based architectural colour research. The purpose of the VCL is to present research results; to develop the forms for such presentations; and to identify the complementary research needed. It enables the user to actively investigate how colours appear in different situations, and provides information on relevant literature and links for further studies. In a questionnaire study, carried out in 2014, two groups of users including architecture students and professionals within architecture, art and design evaluated the usability of the VCL with a combination of qualitative and quantitative methods. The results from the study are accounted for in this article, together with a discussion on how to convey understanding of spatial colour appearance using the web as a medium; and, given the limitations of displaying trustworthy colour appearance digitally, what levels of information in the visualizations are suitable for different target groups.

In this article the focus lies on the questionnaire study, not primarily on the creation, appearance, and functions of the VCL itself. A description of the current version of the VCL is included in The Virtual Colour Laboratory—Basic Design section of the article, but for more thorough information about the project, its background and the problems connected to the translation of paint to digital equivalences, we refer to articles.[24–27]

BACKGROUND

Our project idea was originally to create an interactive virtual environment, opened and used via the web, where users in real time could explore and learn more about indoor and outdoor colour phenomena. Users were first guided through a landscape on a road leading up to the actual colour laboratory building. Along the road were a number of stations, each presenting a specific colour phenomenon, regarding e.g. characteristic aspects of colours in nature; the impact of distance perception on colours; and the coloured materials' interaction with the surrounding landscape. Inside the laboratory, various rooms demonstrated the effects of different choices of colour; light;

*The VCL can be accessed at http://dvfl.portal.chalmers.se/.

†*Colour appearance* is here referred to as a general concept for the perceived colour of a surface.

Fig. 1. The changing colour appearance of a facade according to distance was a central phenomenon to be shown in VCL. The objects in the model were, however, perceived as smaller than in reality and further away, which made the façade hard to notice when approaching it.

pattern; and material. At some stations users could make interactive choices. The graphical user interface displayed written information about the colour phenomenon currently in view, as well as a link to *The Colour Guide*—a pdf file containing further information. In the core of the building was a library, intended to contain relevant links, references and publications; and in the corridor connecting the rooms, surfaces showed 2D-colour phenomena and optical illusions connected to perspective.

The VCL-project originally had the ambition of displaying colour phenomena so that they resembled their real world appearance as closely as possible, with calibration of the monitor as a condition before using the application. In order to achieve this visual realism, substantial studies and comparisons between reality and digital models were conducted. For the methodology used in the process of translating real world colour appearance to digital counterparts we refer to articles.[25,27] However, factors connected to the visualization of realistic colour appearance, combined with spatial differences in virtual settings compared with reality, made it difficult for the application to function as intended. Since a realistic colour appearance could not be accurately reproduced due to this, the problem of visualizing colour phenomena instead became a problem of correctly compensating for the different conditions in Virtual Reality (VR) compared with reality. In the VCL, visual correctness was thus "feigned", though this could only be done since the colour appearance of reality was already known.[25,26]

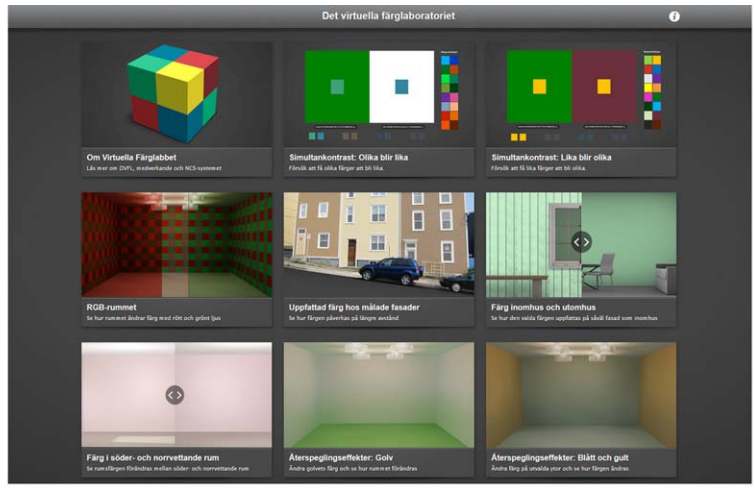
Regarding the spatial differences, there are several problems connected to the spatial experience in a virtual setting. However well made, a virtual environment can never offer the sense of real presence. We do not move around in the same way in a virtual setting as we do in reality, and our attention is not drawn by the same means. A virtual setting consists mainly of sight impressions and active investigation is strongly restricted. To make a user of the VCL observe a specific coloured detailed, or a certain phenomenon, was therefore difficult. This was most obvious in the outdoor model, where a constant problem was that the landscape, meant to look as natural as possible, did not look natural enough. Although it looked sufficiently natural in the software Virtual Map, where it was designed, a significant loss of light and details became visible in the export via 3Ds max to the interactive demonstrator. As a result, much of what in reality is experienced as harmonic became dull and uninteresting in the virtual VCL-model. Furthermore, it was difficult to focus on relevant aspects of what was visualized, since the different parts of the model contained equal visual information with no protruding elements. This problem was also partially connected to the different experience of scale in VR compared with reality. The objects in the model were perceived as smaller, and further away, than in reality (Fig. 1). These combined issues made it necessary to rethink the concept for the VCL. In 2014, a new and simplified version was introduced.

EXPERIMENTAL PROCEDURE

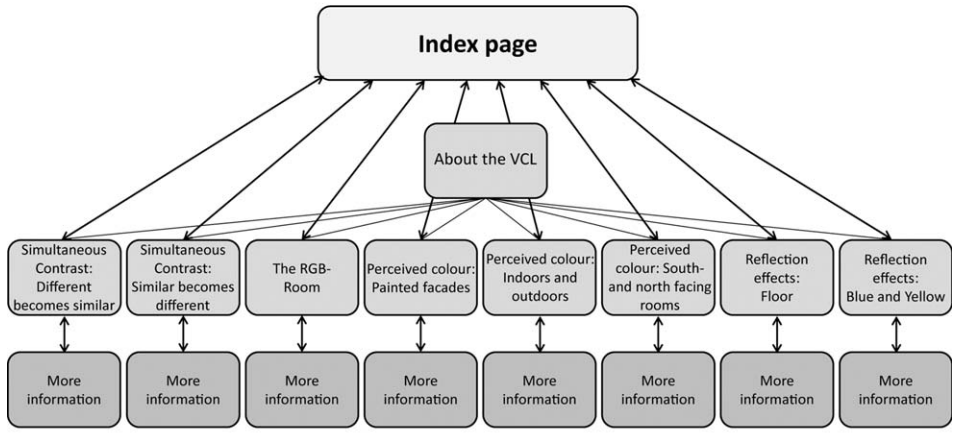
In this section, the preconditions, the design and the set-up of the study are discussed.

The Virtual Colour Laboratory—Basic Design

In its current shape the VCL[28] is a partially interactive web page, so far comprising nine free standing stations, all of which are always accessible from the index page [Fig. 2(A) and 2(B)]. Each station is structured around an exercise on a specific colour phenomenon or principle, using partially interactive visualizations together with a short explanatory text (Figs. 3–10). Here, the user can make choices in order to experience different settings, such as change the colour properties of a surface or change the illumination in a room. Connected to each station is a fly out page providing background information for the demonstrated colour phenomenon (Fig. 11). The text is kept relatively short throughout all stations as an adaptation to the digital medium. For those who want to read more about the subject, each station also provides tips for relevant reading material as well as source material on the research connected to the presented colour



(a)



(b)

Fig. 2. A. The starting page of the VCL showing all the different stations. B. The schematic structure of the VCL website.

Fig. 3. The station About the Virtual Colour Laboratory.

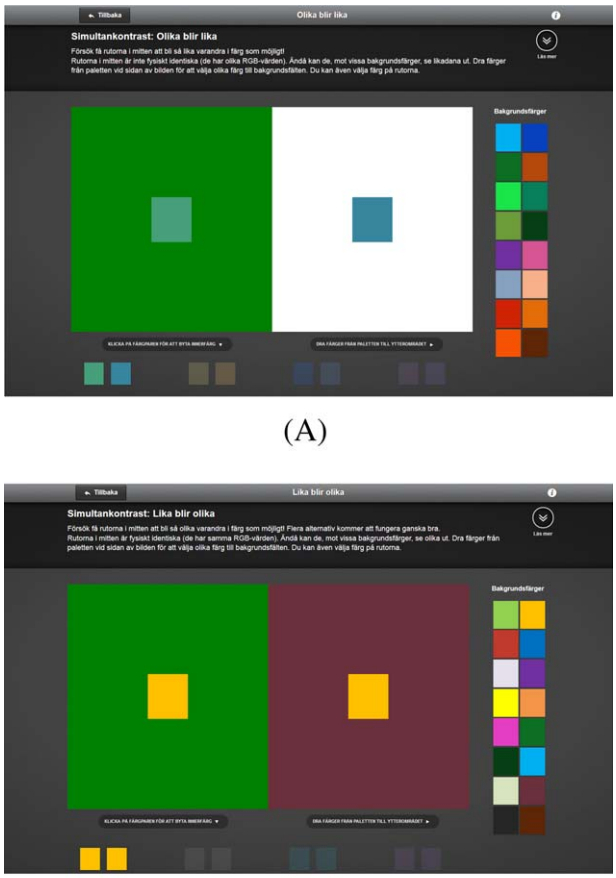


Fig. 4. A. The station Simultaneous Contrast: Different becomes similar. B. Simultaneous Contrast: Similar becomes different.

phenomenon. The current language is Swedish, but a future version of the VCL will also contain an English translation. Since the principle in the current version of the VCL is more about demonstrating tendencies than defining specific values, the decision was made not to include calibration of the screen as a necessary preparation for using the web page. The importance lies not in presenting the colour appearance of each surface correctly, since every display show colours differently, but *the relation* between coloured surfaces, which is generally consistent on different screens.[‡] One effect of this decision, however, is that it has been difficult to visualize specific NCS-values correctly. Therefore, coloured surfaces are mostly demonstrated with the addition of a descriptive name, e.g. light green.

The Stations of the VCL. The VCL currently comprises the following nine stations:

1. About the Virtual Colour Laboratory (Fig. 3) is the introductory station which informs the user about the VCL and the group behind it. It also provides a brief overview of the NCS-system upon which the demonstrated research is based. It is always possible to reach this station when navigating through the other stations in the VCL.
2. Simultaneous Contrast: Different becomes similar [Fig. 4(A)] demonstrates simultaneous contrast. The setting consists of two large background fields, containing one smaller square each in the middle. The smaller squares are not physically identical, i.e., they have different RGB values. The user can experiment with getting the smaller, physically different squares to look as they have the same colour appearance, by changing the colour of the background fields.
3. Simultaneous Contrast: Similar becomes different [Fig. 4(B)] also demonstrates simultaneous contrast. The setting is the same as in the previous exercise, however, in this station the squares in the middle are physically identical, i.e. they have the same RGB-notations. The user can experiment with getting the smaller squares to look as they have different colour appearance, by changing the colour of the background fields.
4. The RGB-Room (Fig. 5) deals with RGB, and demonstrates how, by changing the colour of the illumination from neutral to either red or green, the coloured pattern of the wall surfaces will appear differently. After changing the illumination, it is possible to drag the line dividing the differently illuminated rooms to enhance the comparison.
5. Perceived colour: Painted facades (Fig. 6) demonstrates colour appearance on façades at a distance. The user can choose between six different colour schemes (green, brown, yellow, red, blue, and white) by clicking on a bucket of paint to the right, and consequently see how three different nuances of the chosen paint will look on the adjoining facades at about 50 m distance.
6. Perceived colour: Indoors and outdoors (Fig. 7) demonstrates the fundamental principles of how a paint is perceived when applied on an exterior façade compared with indoor wall surfaces. The user can choose between four different colour schemes (light green, brown, light blue, and yellow) by clicking on the colour samples to

Fig. 5. The station The RGB-Room.

[‡]Through elaborations in the VCL-project we have concluded that the RGB-value of a colour sample is consistent between different screens though its colour appearance may vary.

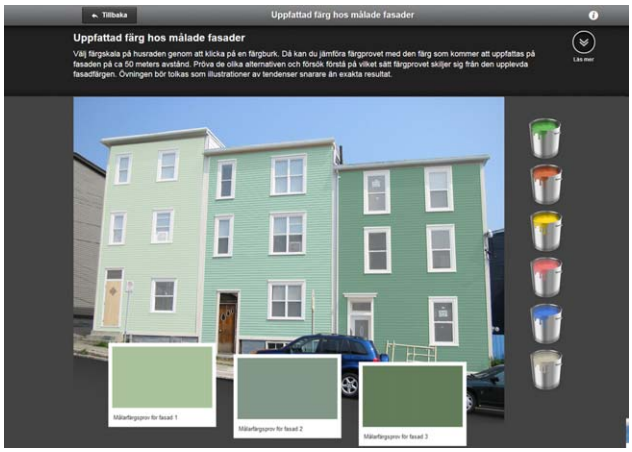


Fig. 6. The station Perceived colour: Painted facades.

the right, and consequently see how the chosen paint is perceived on a façade compared with in a room.

7. Perceived colour: South- and north facing rooms (Fig. 8) demonstrates the difference in colour appearance in rooms facing different directions. Both the perceived colour and the character of the room change between a south facing room with direct sunlight, and a north facing room without direct sunlight but with plenty of daylight. The user can chose between four different colour schemes (pink, yellow, light green, and light blue) by clicking on the colour samples to the right. It is then possible to make further choices between four different nuances of the selected colour scheme, and consequently see how the chosen paint is perceived in a south- compared with a north-facing room.
8. Reflection effects: Floor (Fig. 9) deals with interreflections within a spatial setting. This station demonstrates how surfaces in a room are affected by the reflections from the floor. The user can paint the floor in one of six different hues (gray, blue, green, yellow, brown, and magenta) by clicking on the colour samples to the right. The room lacks furniture in order to demonstrate the principle more clearly.
9. Reflection effects: Blue and Yellow (Fig. 10) also deals with interreflections within a spatial setting. This station allows the user to change the colour on different room surfaces and see how this will affect the room as a whole. The surfaces are painted either yellow or light blue (except for the ceiling which is white), and there are six different combinations to choose from in order to see how the reflections of the surfaces affect the colour appearance of the room.

Technical Data

In their current shape, the stations of the VCL are based on model images constructed in 3Ds max, Cinema 4D, and Adobe Photoshop; and are the result of thorough studies of colour phenomena in real world environments. Adobe Photoshop and the web-based NCS Navigator[29] have been used in order to correct the colour appearance on the rendered textures and images. The graphical content in the graphical user interface, e.g. images and icons, was created in Adobe Photoshop. Regarding the coding of the web page, HTML was used in order to create all included elements such as text, images, links and buttons. CSS was used for setting typeface, colouring and positioning of objects on the page. Javascript was used to make the objects moveable and PHP for giving the page functionality.

The Subjects

The subjects were divided into two categories: Group 1 contained professionals within the areas of architecture, design, lighting design, art and interaction design. Group 2 contained first year architecture students. For the first

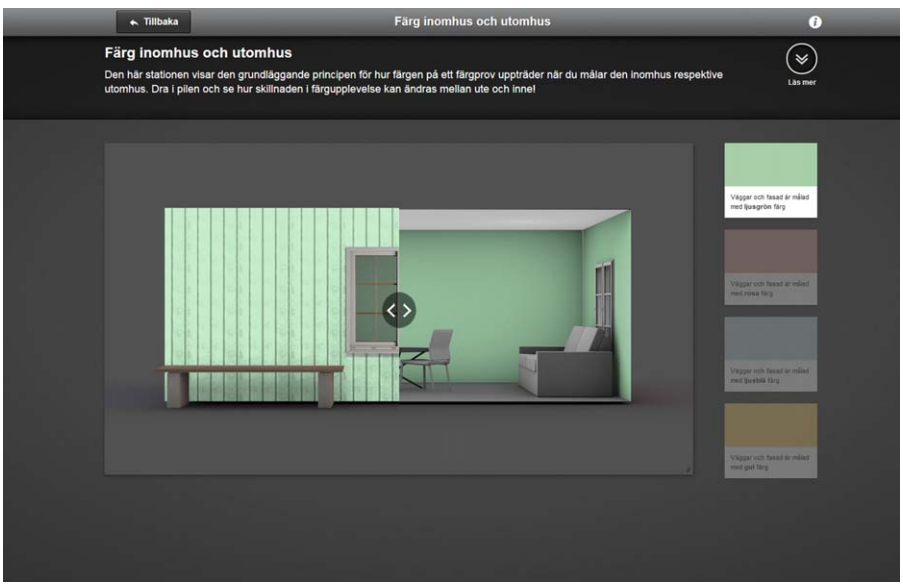


Fig. 7. The station Perceived colour: Indoors and outdoors.

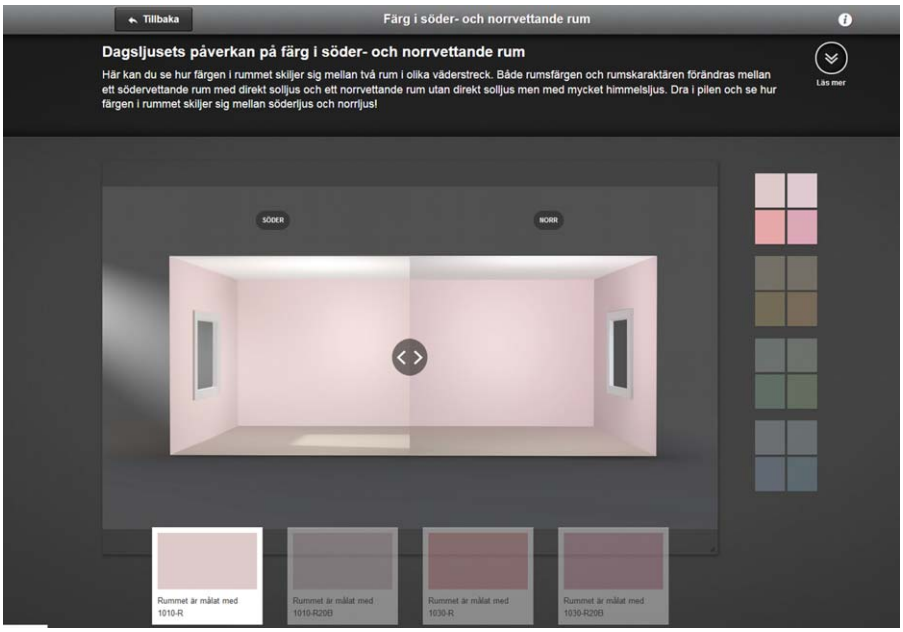


Fig. 8. The station Perceived colour: South- and north facing rooms.

category, the questionnaires were sent out via e-mail to 31 individual professionals, from whom 25 answered that they were willing to participate and 20 sent in a completed questionnaire. For the second category, 90 students (the first year class of the Architecture program) were asked directly if they wanted to participate in the study. In this category 35 were willing to participate, and 25 sent in a fully completed questionnaire.

The Questionnaire

The questionnaire was divided into three sections. The first section concerned the personal and professional profile of the participants, while the second focused on their experience of working with and their use of colours. The third and biggest section concerned the actual evaluation of the colour laboratory. For this section, the users were given the link to the webpage. They were expected to have familiarized themselves with the content before proceeding with answering the questions. A combination of qualitative and quantitative approaches was applied throughout the questionnaire. For the evaluation of each separate station, the following evaluation techniques were used:

1. Semantic differential scaling. The participants were asked to mark the importance of different characteristics for each station (pedagogical value, included images,

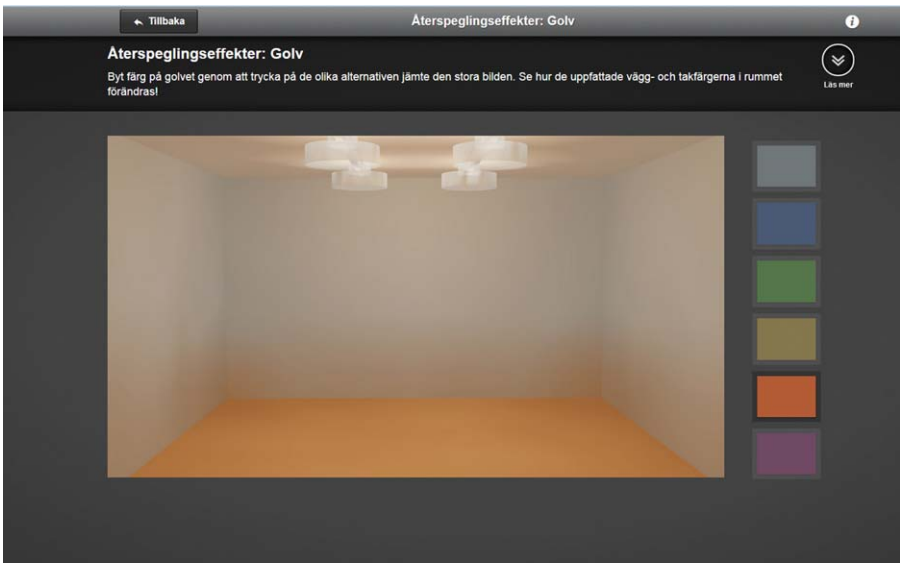


Fig. 9. The station Reflection effects: Floor.

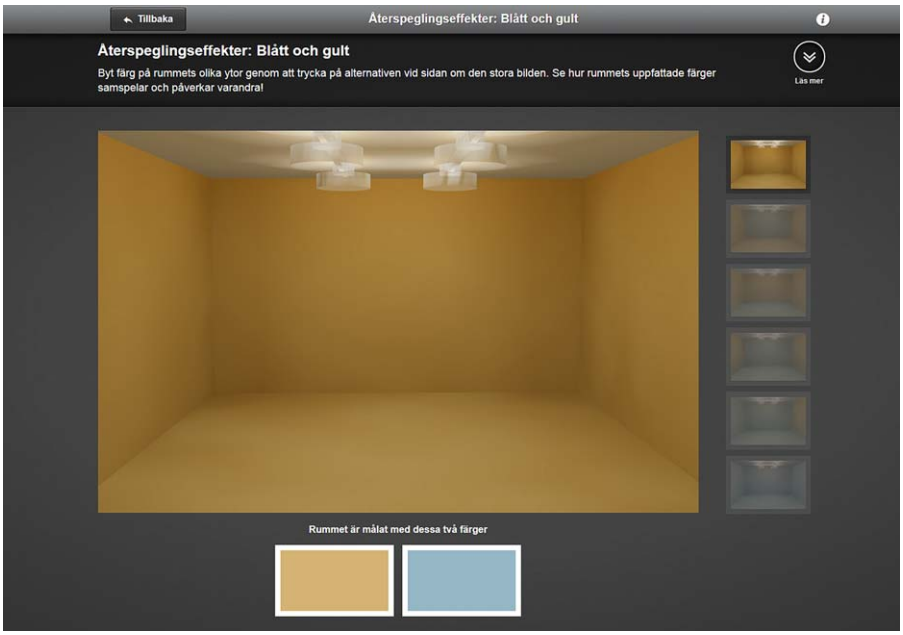


Fig. 10. The station Reflection effects: Blue and Yellow.

included text, set-up and general impression) on a 7-grade scale ranging from −3 (very bad) to 3 (excellent). As a complement to this, the participants were given the opportunity to comment on their choices.

2. Answers of a yes/no/don't know character in response to questions concerning the relevance of the station for the user.
3. Free views and comments on each station, according to specific criteria. This included, for example, how interesting and useful the content was; how pedagogical the station was; how comprehensible the images were, and how the text was perceived.
4. Free comments on each station were encouraged as an important supplement to the scaling questions.

In the last part of Background section, questions concerned which station the user found functioned best, according to some specific criteria. Here choices of one or more stations were combined with free comments as an explanation for each choice.

RESULTS

In this section, the results from the different parts of the questionnaire are presented.

Fig. 11. Example of one station's flyout page, providing background information on the demonstrated colour phenomenon.

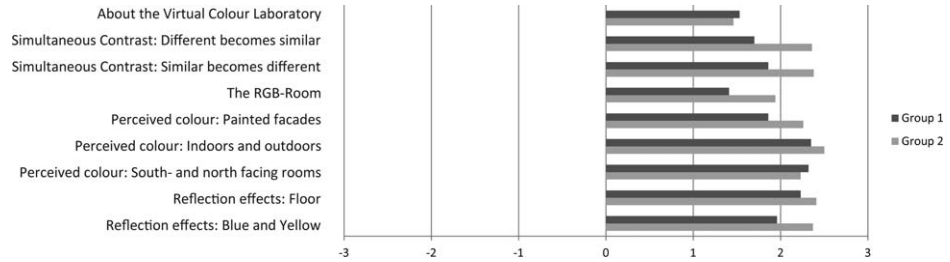


Fig. 12. The combined mean value of all answers for the five criteria Pedagogical value; Readability; Visual clarity; Structural clarity; and General impression. Semantic scaling was used, ranging from −3 (very bad) to 3 (excellent).

Part 1 and 2 of the Questionnaire: Target Groups and their Colour Knowledge and Experience

Part 1 of the questionnaire regarded the personal and professional profile of the participants, while Part 2 concerned their knowledge of colour appearance and their experience of working with colour.

In group 1, 20 professionals within the areas of architecture, design, and art participated. 16 of these were occupied within research and/or teaching at post-secondary and/or university level. Nine were architects and/or designers, six were artists, and two were categorized as "other." Out of the 20 there were 15 women and 5 men. The age of the participants varied from 32 to 67 years, with an average of 49.4 years. All of the participants professionally worked with, and had a great interest in colour. Almost all of them (19 out of 20) had a large to very large colour knowledge. 75% had more than 20 years of colour experience, 15% had 10 to 20 years of colour experience, 5% had 5 to 10 years, and 5% had 0 to 1 year.

In group 2, 25 first year architecture students participated; 19 women and 5 men. The age of the participants varied from 18 to 31 years, with an average of 22 years. All of the subjects had some basic colour training, including the NCS-system, through their architecture education. A few of them also had additional training from art schools; 60% had 0 to 1 year of experience, 20% had 1 to 2 years, and 20% had 2 to 5 years of experience. Most of the subjects (76%) had limited colour knowledge, while 24% had a larger amount.

Part 3 of the Questionnaire: Evaluation of Each Station Separately and the VCL as a Whole

In the third part of the questionnaire an evaluation was made of each station and of the VCL as a whole.[§,¶]

Evaluation of Each Station Separately. The subjects were asked to evaluate each station from the criteria (1) pedagogical value; (2) readability; (3) visual clarity; (4) structural clarity; and (5) general impression using semantic scaling ranging from −3 (very bad) to 3 (excellent). The predominant result showed that the VCL generally was highly appreciated by the users in the study (Fig. 12), although the assessed quality of the stations differed. Moreover, there was a common tendency for group 2 (the students) to be more unified in their answers compared with group 1 (the professionals). Group 2 also, generally, rated the stations higher than group 1 for the different criteria. This tendency was particularly evident in the combined ratings of the stations Simultaneous Contrast: different becomes similar [Fig. 4(A)]; Simultaneous Contrast: similar becomes different [Fig. 4(B)]; The RGB-Room (Fig. 5); Perceived colour: painted façades (Fig. 6); and Reflection effects: Blue and yellow (Fig. 10), all of which were given significantly higher ratings from group 2, compared with from group 1. The generally highest ranked station for group 1 and group 2 together was Perceived colours: Indoors and outdoors (Fig. 7) which most observers found both interesting and useful. For group 1, the lowest rated station, by a significant margin, was the RGB-Room, which observers considered slightly over explicit and too basic. For group 2 also, the RGB-Room was rated lowest, though it was notably more highly rated than by group 1. The only two comments in addition from group 2 concerned size and interaction of the visualization.

The evaluation of the five criteria separately shows the same tendency for group 2 to rate most of the stations more highly than group 1. This difference in ratings is particularly striking for the station Perceived colour: Painted façades (Fig. 6) concerning the criterion Structural clarity (Table I). Comments from group 1, in addition to their semantic scaling ratings, reveal a spread in opinions, where most are positive about the content and structure of the station, with a few exceptions that call for better interaction and clearer structure in the exercise. The semantic scaling ratings for group 2 show that the students are more collectively positive towards the structure of this station, however they do not leave any additional comments.

There are only a few cases where group 1 rates a station higher than group 2, including Perceived colour: South- and north-facing rooms (Fig. 8) for the criteria Pedagogical value and Readability (Table II). Comments from group 1 show that this station is engaging and raises an interest in the demonstrated phenomenon. Many suggestions on visual improvements for the exercise are given. In group 2 darker colour samples are called for to elaborate with in the

[§]Some participants did not answer one or more of the questions, and therefore the numbers of answers which are accounted for in the results vary between 16 and 20 for group 1, and between 13 and 25 for group 2.

[¶]Important to note is that participants sometimes stated more than one alternative in their answers. For the statistical analysis we have therefore discarded these answers.

TABLE I. Mean value and standard deviation for groups 1 and 2 regarding the criterion Structural clarity for the station Perceived colour: Painted façades.

Structural clarity	Group 1	Group 2
Mean value	0.32	2.42
Standard deviation	1.79	0.97
Responses	19	24

exercise, as well as photos from real life situations. About the Virtual Colour Laboratory (Fig. 3) is also rated higher by group 1 than by group 2 for the criteria Readability and Structural clarity (Table III). Comments from the groups concern, above all, the layout of this station, which is considered, despite having interesting content, a bit too dense and hard to read.

There was a concordance between the groups rating Perceived colour: Indoors and outdoors (Fig. 7) highest for the criterion Visual clarity. Participants from group 1, though liking the general idea and written content of this station, call e.g. for a higher degree of detailing in the visualizations and NCS-codes for the demonstrated paints. Comments from group 2 call for photos with examples from reality, and for more colour samples to compare. When it comes to the criterion General impression, all stations are rated high by both groups. The highest rated stations for group 1 regarding this criterion are Perceived colour: Painted façades (Fig. 6); Perceived colour: Indoors and outdoors (Fig. 7) and Perceived colour: South- and north facing rooms (Fig. 8), while group 2 rates About the Virtual Colour Laboratory (Fig. 3); Simultaneous Contrast: Different becomes similar [Fig. 4(A)]; Simultaneous Contrast: Similar becomes different [Fig. 4(B)]; and Perceived colour: Indoors and outdoors (Fig. 7) highest.

The participants were also asked to evaluate which station or stations they considered to work best pedagogically (Fig. 13), as well as to give the best understanding of colour appearance (Fig. 14). They were asked to choose one or more stations for each question, adding comments as support for their choices.

The station that in group 1 was found to be best working pedagogically (Fig. 13) was Perceived colour: Painted façades (Fig. 6) (18%), followed by Simultaneous Contrast: Similar becomes different [Fig. 4(B)] (16%) and Simultaneous Contrast: Different becomes similar [Fig. 4(A)] (14%). Comments in connection to this stated that the stations on simultaneous contrast "offer more ways of 'teaching myself,' and 'offer a smooth and easy way to let colours interact on the screen, instead of cutting coloured paper, or mixing colours on a palette!'" Many comments stated that they found these stations clear and straight forward. A few found them over-pedagogical.

TABLE II. Mean value and standard deviation for groups 1 and 2 regarding the criteria Pedagogical value and Readability for the station Perceived colour: South- and north-facing rooms.

Pedagogical value	Group 1	Group 2
Mean value	2.39	2.13
Standard deviation	0.85	1.39
Responses	18	24
Readability	Group 1	Group 2
Mean value	2.56	2
Standard deviation	0.92	1.29
Responses	18	24

TABLE III. Mean value and standard deviation for groups 1 and 2 regarding the criteria Readability and Structural clarity for the station About the Virtual Colour Laboratory.

Readability	Group 1	Group 2
Mean value	1.58	1.08
Standarddev.	1.77	1.32
Responses	19	13
Structural clarity	Group 1	Group 2
Mean value	1.32	0.72
Standarddev.	1.53	1.41
Responses	19	18

In group 2, Simultaneous Contrast: Different becomes similar (21%) got the highest marks on the same question, followed by Perceived colours: Painted façades (15%), and Perceived colour: Indoors and outdoors (Fig. 7) (15%). Comments in connection to this stated that the exercise in Simultaneous Contrast: Different becomes similar was fun and motivating to work with and that the text explained the content well. One participant remarked that the station very clearly showed how colour surfaces affect each other. Another participant wrote that the station pointed out a phenomenon that "I think most will be surprised over, at least I was." Regarding Perceived colour: Painted façades comments stated that this station raises an interest, though "one understands what it is about, without reading the text"; and "It is clear and extra user friendly." Perceived colours: Indoors and outdoors was perceived as extra clear and usable, and experienced as trustworthy.

Regarding which station or stations that group 1 considered provided the best understanding of the appearance of colour (Fig. 14). Perceived colour: Painted façades got the highest ranking, closely followed by the station Simultaneous contrast: Different becomes similar. Several of the participants in group 1 found that these stations were clear and simple, and easy to understand. Comments read that they worked well on the screen, and that in Simultaneous contrast: Different becomes similar "the colour appearance on the screen was undisturbed by all the affecting light sources of reality." One participant noted that these stations increased his/her will to better understand colour appearance, and provided increased insight into colour phenomena. Others mentioned that the interaction added value, that the text was good and explicable, and that the real world examples in

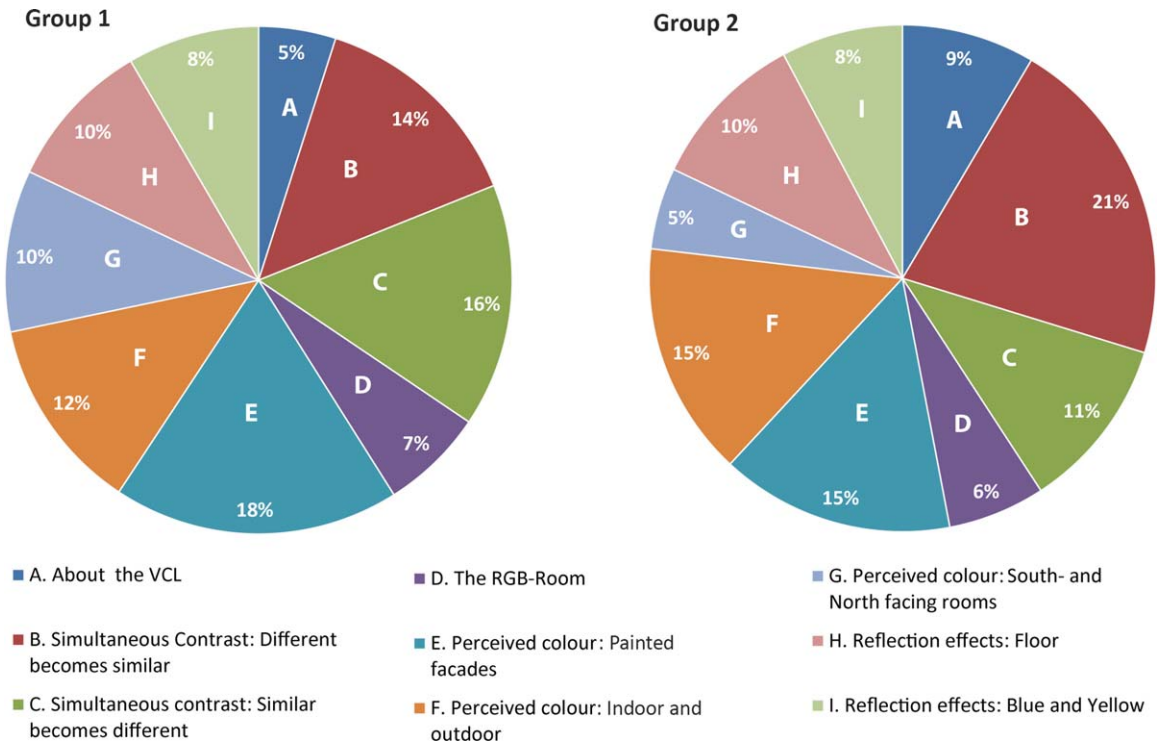


Fig. 13. Evaluation of which station is considered as best working from a pedagogical point of view, shown in percentage.

Perceived colour: Painted façades were easiest to relate to. In group 2, Simultaneous contrast: Different becomes similar got the highest rankings. The next two highest ranked stations were Perceived colour: Painted façades and Perceived colours: Indoors and outdoors. One participant remarked that these stations "describe different ways that colours behave which you don't normally think about, and which is useful both in an everyday context and professionally" and another that these stations focused on "the questions I sometimes think about

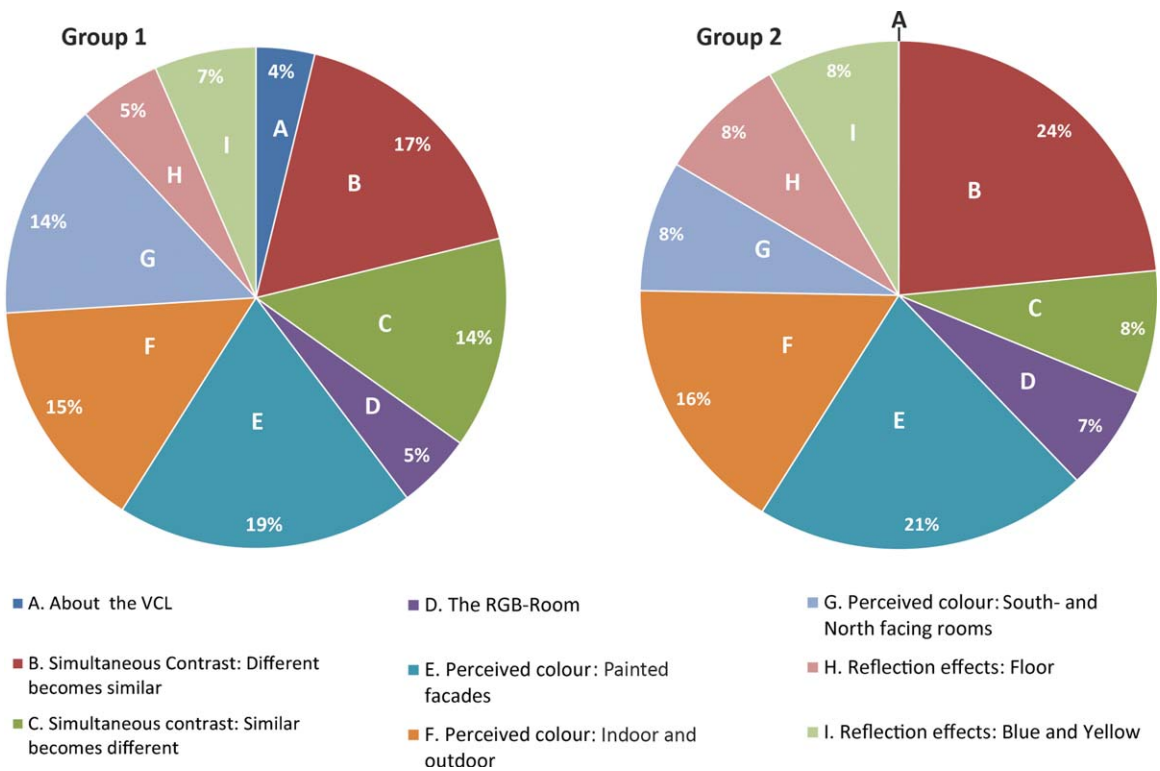


Fig. 14. Evaluation of which station is considered to provide the best understanding of colour appearance, shown in percentage.

TABLE IV. Evaluation for group 1 (left) and group 2 (right) regarding whether or not the content of each station was (1) interesting, (2) relevant, and (3) knowledge generating.

		Group 1:			Group 2:		
Stations:		Content interesting?	Content relevant in your work?	Content generating new knowledge to you?	Content interesting?	Content relevant in your work?	Content generating new knowledge to you?
About the Virtual	Yes	18	15	7	25	25	20
Colour	No	0	0	11	0	0	2
Laboratory	Don't know	1	3	2	0	0	3
Simultaneous	Yes	18	14	5	24	24	20
Contrast:	No	0	1	9	0	0	2
Different becomes similar	Don't know	0	2	4	0	0	2
Simultaneous	Yes	19	16	5	24	25	20
Contrast:	No	1	2	14	0	0	3
Similar becomes different	Don't know	0	2	1	0	0	2
The RGB-Room	Yes	14	11	5	15	20	16
	No	2	5	12	4	0	5
	Don't know	3	4	3	5	4	3
Perceived	Yes	17	13	10	25	25	20
colour:	No	1	4	7	1	0	4
Painted facades	Don't know	1	2	2	0	0	1
Perceived	Yes	17	14	11	24	25	19
colour:	No	2	3	8	1	0	5
Indoors and outdoors	Don't know	0	2	0	0	0	1
Perceived	Yes	15	12	6	24	24	23
colour: South-	No	1	3	10	1	1	2
and North-facing rooms	Don't know	0	2	0	0	0	0
Reflection	Yes	19	13	6	22	24	20
effects: Floor	No	1	5	13	0	1	4
	Don't know	0	2	0	3	0	1
Reflection	Yes	16	14	5	24	24	23
effects: Blue	No	2	2	12	0	0	2
and Yellow	Don't know	2	4	2	1	1	0

A few participants sometimes stated more than one alternative in their responses. For the statistical analysis we have discarded these answers. Moreover, some participants did not answer all of the questions. Therefore, the number of responses varies between 16 and 20 for group 1, and between 24 and 25 for group 2.

regarding colour." Many commented that these stations most clearly demonstrated differences in colour appearance depending on circumstances, and most concretely displayed how coloured surfaces are affected by light and surrounding colours.

The two groups were further asked to evaluate the content of each separate station from the criteria (1) Is the content interesting?; (2) Is the content relevant to you in your work?; and (3) Is the content generating new knowledge for you? (Table IV). From a compilation of all answers (Fig. 15), it is evident that both groups, particularly group 2, considered the project to be interesting and relevant. However, the largest difference between the groups concerned the question of whether the VCL generates new knowledge for the user or not. The largest part (80%) of group 2, consisting of the students, considered it to do this, compared with 55% of the professionals in group 1, who did not. In group 1 there was a larger spread in answers, indicating a more mixed response.

Evaluation of the VCL as a Whole. On a scale ranging from −3 (very bad) to 3 (excellent) regarding how they perceived the VCL as a whole, a majority of both groups rated it highly (Fig. 16). Most of the comments were positive about the VCL, showing for example that participants thought the VCL "a valuable simple form of practical knowledge mediation," "fun, and a simple way to discover great differences [in colour appearance]," "giving fast, concrete examples of the complexity of colours," and "making it possible to understand how colours affect each other which it is not possible to learn via text alone." Others gave constructive criticism, for example that the VCL "so far is not nuanced enough," "does not provide enough new knowledge," "needs a bit of sharpening," and "has a middle-level which reaches neither the inexperienced nor the experienced." A few noted that the mediation of colour appearance via digital media was a problem.

The larger part of group 1 (the professionals) could see the meaning of using the VCL as a pedagogical tool in their work (group 2, only consisting of students, was not

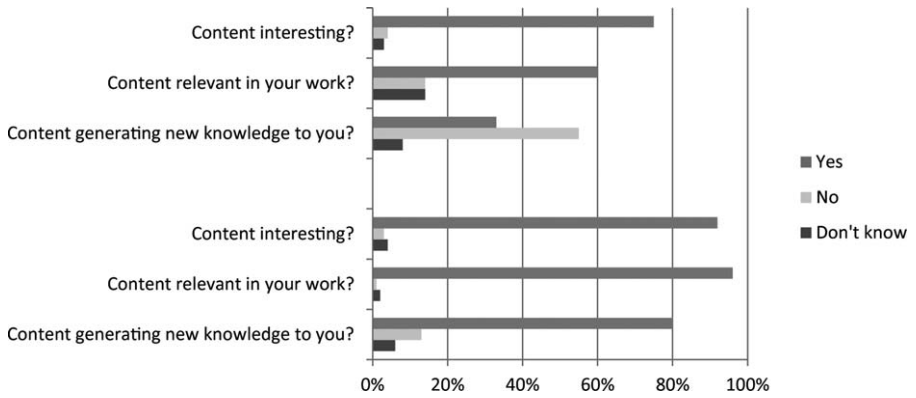


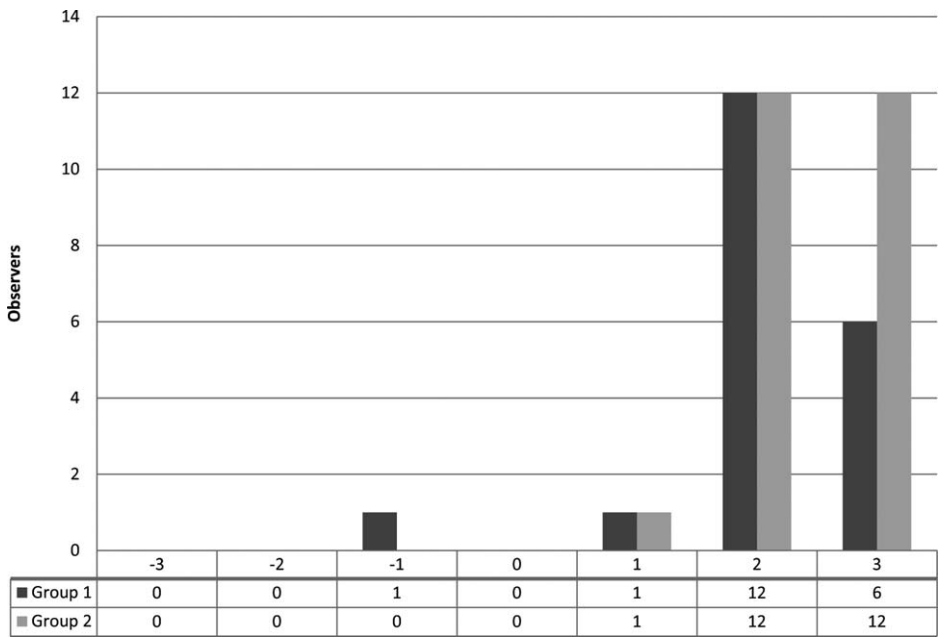
Fig. 15. A compilation of all answers from groups 1 and 2 regarding how interesting, relevant and knowledge generating they consider the VCL to be, shown in percentage.

asked this question). Many of the teachers within group 1 stated that they were positive about using the VCL as a complement to their teaching, giving comments such as "students can elaborate on their own, without already given answers", and that "the stations are often pedagogical and clear, and would be a good complement [to the teaching]." Other participants stated that they would recommend the site to those interested in colour.

Regarding suggestions on improvements for the VCL, the participants in both groups commented on aspects such as design and graphical user interface, usability, content, target audience and level of interactivity. Both increased and reduced interactivity was called for, as well as increased complexity in, as well as more, exercises. A few participants from both groups asked for more realistic looking settings for the room stations, including more detailing such as furniture and visible light sources etc. In group 1 more detailing and the use of NCS-coding was called for, as well as a better colour adaptation to digital media. Participants from group 2 asked for more facts and explanations on colour appearance, more colour samples to choose from in the stations, clearer instructions and pop-up signs when an elaboration was successfully completed with information on why it worked.

DISCUSSION

As we move further towards a digitalized society, using visualization as a tool for pedagogical learning is becoming increasingly common, and the advantages of using this new medium for communicating ideas are many. However, computer generated visualizations can in some ways lead to misunderstandings between the designer and the recipient, originating from the appearance of the visualization itself. Today's technology allows visualizations so realistic in appearance that they are hard to tell apart from the real thing, and can thus convey any message, truthful or not. Visualizations aiming to be realistic, but



	-3	-2	-1	0	1	2	3
Group 1	0	0	1	0	1	12	6
Group 2	0	0	0	0	1	12	12

Fig. 16. Ratings using semantic scaling ranging from −3 (very bad) to 3 (excellent) for how the observers experienced the Virtual Colour Laboratory as a whole. Nineteen observers answered this question from group 1, and 25 from group 2.

which are not realistic enough, can create focus on the faults in appearance rather than on the intended design. The challenge thus lies in conveying the design idea as accurately as possible, while at the same time visually minimizing false interpretations. In the VCL-project it has from the start been a challenge to find the correct level of detail and information in the visualizations. Combining visual correctness with pedagogical accuracy has been a focus in the project. Technological issues and limitations, including the difficulties of translating real world colour appearance to a digital setting, have led to a lower degree of photorealism in favor of the principle of the exercise being more clearly demonstrated. But what level of realism is enough in pedagogical demonstrations of this kind? The more knowledge you possess on a subject, the higher your demands for detailed precision will be. In this study it has proved important to consider the qualitative follow up to each quantitative answer from both groups. Comments from group 1 (the professionals) revealed a higher sensitivity to the visual exactness of the presented material, and called among other things for NCS-codes for all the colour samples used in the demonstrations and exercises. Group 2 (the students) generally accepted a lower degree of visual exactness, and instead tended to comment on the stations' capacity to convey the information, as well as the interactivity. Other calls regarding the visualizations of the VCL concerned more detailing, and more options in many of the exercises; as well as sometimes a higher, and sometimes a lower, degree of interactivity.

There was a general tendency for group 2 to be more concurrent than group 1 in their answers, as well as frequently rating all stations more highly for the different criteria, as was particularly clear in the evaluation of the stations Simultaneous Contrast: Different becomes similar and Simultaneous Contrast: Similar becomes different. One explanation for the high ratings of these particular stations can be that the students had had a course in colour theory in the weeks before the survey, and through this had the analog versions of the Josef Albers-based exercises presented in these stations fresh in their minds. It also suggests that the tool is pedagogically functioning as intended in these two stations.** However, group 2 though giving higher ratings were not prone to give many comments on their evaluation. Group 1, though generally being a bit more critical, were more reflective and gave much feedback.

One plausible reason for the generally higher spread in answers for group 1 could be that this group consisted of professionals from varying fields connected to colour. While the students in group 2 had not yet started their individual careers, and were all at the same stage in the same education, the professionals did not have a uniform educational background and worked within various different fields connected to architecture, art and design, thus constituting a less homogenous group than group 2. Their evaluation of the tool from their role as professionals within the field of colour could be a reason for the amount of often very detailed comments and criticism, in many cases connected to their own experience, which they provided; compared with group 2 in which the observers generally gave the stations higher ratings, but rarely explained the reasons for their choices. Analyzing the background of the commentators, the conclusion is drawn that the VCL might not be as relevant as a pedagogical tool for artists and in art education, as in design and architectural teaching, since the focus of the exercises currently lies on colour appearance in the built environment.

**Noteworthy is that Simultaneous contrast: Similar becomes different and Simultaneous contrast: Different becomes similar are demonstrating the same exercise, from two angles, which might lead to the conclusion that participants choosing one of these also include the other in their choice.

CONCLUSIONS

Though published user studies for this kind of tools so far are few in number, the use of digital demonstration tools for educational purposes is constantly increasing, making this study highly relevant. The VCL has been a small project, with high aspirations but with a limited amount of time. In spite of this the user evaluation shows high appreciation of the tool and great potential for this kind of pedagogical aid. In this user study we got a clearer image of how the VCL is perceived by potential users, and what adaptations that could be useful to make in order to meet relevant suggestions regarding e.g. interface and interaction. The high ratings for some of the stations point towards the tool working as intended in these, and they can thus be looked upon as guidance in the further development of the VCL.

What we have learned from this evaluation is that the VCL probably functions best as a pedagogical tool when used as a complement for a teacher giving a lecture or a workshop, and as such it has the potential to be developed further. The evaluation made by the observers, and particularly their qualitative comments, have been very valuable when considering both the design and content in the future development of the VCL.

Future Work

The VCL is an on-going project with great potential to become a useful NCS-based demonstration tool within colour education for designers and architects. In this development, the results from the user study need to be considered, both regarding content, structure, graphics, and user interaction of the site. A possible future development could be to include results from other research areas connected to colour appearance, for example illumination, as well as visual illusions. In order to make the site more dynamic, the VCL could also be expanded to include the possibility to give feed-back and comments directly on the website, and perhaps also provide a forum for exchanging ideas and opinions in connection to the

presented material. First however, we want to broaden the VCL with more stations on spatial colour phenomena. In this development we invite other researchers to contribute with their research, existing or in progress, to form a base for new stations and also for an international collaboration.

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