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A novel approach to colour education and comparative testing of physical and digital versions

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This paper begins with an educational problem: the defects in how colour is often taught. It then uses educational theory to suggest an analysis of the problem in terms of a failure to connect learners' personal experiences of colour to the theories being taught. It then describes the development of a promising method of learning HSB colour theory. Observations from a comparative study between this activity-centered learning method and learning from text are then discussed. Finally we outline the advantages and disadvantages of using advanced 3D technology in color education, a preliminary version of which we also developed and tested.

1. Introduction

This paper describes what was learned from the first stage of a project to develop an improved method of learning and teaching colour, which will eventually involve the application of 3D computer technology. The primary aim of this research was not simply to use computer technology for teaching colour, but to design and implement a novel teaching approach that could offer satisfying learning outcomes and increase learners' motivation and enjoyment. We have developed an initial version of the method and run a preliminary trial of it on learners, comparing the new method with learning from an excerpt from textbooks.

In order to improve the learning and teaching of the selected topic, in this case the Hue, Saturation (or Chroma) and Brightness (or Value) or HSB colour space, and to successfully implement the use of technology, we pursued the following strategy:

1. First identify an existing problem. Replacing teaching that already works adequately is not likely to lead to worthwhile improvements.

2. Analyse the existing problem using educational theory.

3. Propose a solution by initially developing a human tutoring method. A human tutoring approach allows rapid changes and improvements as well as detailed observation of the learning and learners. Having a human simulate what will eventually be done by a computer, the so-called "Wizard of Oz" technique (Kelley, 2005; Preece et al., 1994, p.541), is an established rapid prototyping technique in Human Computer Interaction.

4. Develop the technological solution: convert the human teaching into software.

5. Experimental testing of alternative solutions e.g. existing textbooks versus the human tutoring versus the technological version.

2. Colour Education

Recent changes in the art and design curricula have affected the topic of colour among others. It is currently often integrated into other subjects and occasionally not taught at all, even in programmes where it is important to students' subsequent professional practice e.g. art and design and architecture (Bergstrom, 2001). That has been the case with other subjects that were traditionally taught in a studio environment. The significant increase of student numbers in art and design courses has made studio-based instruction difficult to maintain, resulting in the shift of these subjects to less practice-based teaching methods or to workshops running only for one or two weeks, usually in the first year, leaving no time for reflection and experimentation.

Another reason for degrading or excluding certain subjects from the curriculum is the introduction of newer subjects that emerged from the development of technology and the digital media. Nowadays art and design embrace many different areas, ranging from painting to interactive multimedia design, so the integration of modern subjects and technologies is necessary.

Colour education on the other hand has not notably evolved. For more than fifty years, most of the course assignments on colour in most art and design universities have been based on Josef Albers' book "Interaction of Colour" (Albers, 1975). Undoubtedly, Albers' practical colour experiments were and still are valuable for developing a sense for colour and learning about the interrelations of colour as they address the important issue of "perception", avoid scientific explanations, and encourage experimentation. Traditional theories and skills, however, cannot be applied to a range of digital media while a need for digital colour management has become evident (Kim & Chung, 2005). The absence of updated colour teaching material has not only affected the arts but other fields such as computer science, informatics, vision science (Schanda et al. 2002), psychology, neurology, etc.

But why is colour education important? Students often argue that colour theory is mostly relevant to people who will become painters and they feel that rules of harmony restrict the use of colour in their works. Nevertheless, colour education is in fact more important than ever in light of the quantity of colour stimuli we are exposed to every day and the range of products available (e.g. metallic, glowing, iridescence, phosphorescent pigments, coloured light sources, etc). A colour course could provide students with confidence and skills, and fuse experimentation and creativity. Furthermore, it promotes communication by establishing a universal colour vocabulary (Spalter et al. 2000).

Too often a course may consist mainly of lectures and notes presenting highly abstract concepts, such as hue, saturation, brightness, simultaneous contrast, subtractive and additive mixing. Didactic lectures on colour theory, with no visual teaching aids or practical activities, can lead to surface learning, where students do not connect the theoretical concepts to real life situations. Black and white textbooks can be ineffective for building connections between symbols and visual recollection of colours, effects or illusions. In such cases, learners find it difficult to master the concepts and hard to get motivated.

On the other hand, some courses on colour are based on practical activities, excluding entirely the theoretical aspect. When practical assignments are not linked to any theory, they can lead to limited learning that does not transfer or generalise well. Students tend to concentrate more on how to mix paints accurately and to cut out colour samples from magazines than actually reflecting on the purpose of the exercise.

Some universities have developed digital learning environments, whether web-based or media-based (CD, DVD), for teaching colour theory (e.g. Exploratories[1], Chromascope[2], ART 302 Color Design[3] and Hongik Digital Color[4]), although few have evaluated the effectiveness of the digital learning environment. From a pedagogical, as opposed to a technological, viewpoint, only a few could be said to have used the possibilities of computer technology to create innovative applications and exercises that modify and update the way colour is being taught.

What is wanted is a way to support the learning of colour that relates theory and practice: involving personal experience and action (in the spirit of studio-based teaching) with some basic theoretical concepts, without requiring large amounts of time from teaching staff.

3. Analysis of the problem using educational theory

Educational theory suggests that a better balance between theory and practice should result in a learning experience that is both more effective and more enjoyable. The most frequently mentioned educational concept is constructivism (Larochelle et al. 1998). According to this theory, people do not just receive or reproduce, but actively (re)construct, new knowledge and understanding founded on what they already know and believe. This is also expressed in Laurillard's model (1993) of the teaching and learning process, which asserts that all well-designed teaching will attend equally to both the public, abstract, conceptual aspects and to the private, concrete and experiential aspects of a topic, and also to creating connections between them.

In fact it is desirable to connect new ideas being taught to three things. Firstly, to the prior concepts (whether right or wrong) the learner may have embraced. Secondly, to their prior experiences of colour and of using colour, especially since people experience colour from a very early age: it is not sensible to try to teach even a simplified theory that cannot deal with facts that the learner already knows. Thirdly to their present experiences: although some learning occurs without any actions being performed, it is also clear that important learning occurs through attempting tasks. Therefore, it is necessary to align learners' tacit knowledge (prior concepts) of the subject matter with the new theoretical knowledge being offered by applying the theory in practice. Educators need to build on these personal conceptions and experiences in ways that assist learners to achieve a deeper understanding of the subject. Inglis et. al (1999) argue that education can go wrong when theory is

[1] http://www.cs.brown.edu/exploratories/freeSoftware/catalogs/color_theory.html
[2] http://www.ncscolour.com/webbizz/mainPage/main.asp?unit=Chroma
[3] http://web.ics.purdue.edu/~pbendito/color_design/index.html
[4] http://digitalcolor.cyworld.com

separated from practice and/or when barriers between them prevent this interplay. Since colour is a perceptual experience, this is both important and relatively easy to arrange.

Research also suggests that learners are more motivated when they can see the usefulness of what they are learning and when they can use that information to do something (Lambert & McCombs, 1998). Likewise, skills are learned more effectively when the learner is aware of the need for them and has a personal interest in acquiring them (National Research Council, 1999).

Thus in general, the design of learning materials should be preceded by an investigation into what the target learners typically think, rightly or wrongly, about the topic. It should also include practical activities where possible, partly because people learn by exercising the ideas they are trying to learn, but even more in order to link the theory to practical experience.

Laurillard (1993) also emphasises the importance of a dialogue between the teacher and the learner where the teacher can analyse the student's conceptions on a certain subject and determine the future nature of the dialogue depending on these ideas. However, the increase of student numbers within the studio environment has rendered face-to-face communication among teachers and students a scarce resource. Since most of the art and design subjects are based on knowledge construction and not fact learning, dialogue and externalization of ideas and problems is used for creating challenges, generating healthy arguments and encouraging students to further express themselves verbally, textually or visually. Thus, a digital learning environment designed to generate productive questions and arguments could propel learners to reconsider their actions and encourage them to use their existing knowledge to understand new concepts.

4. The tutoring method

We therefore developed a teaching method for our chosen topic of the HSB colour space that consisted of a set of exercises in arranging colour samples guided by a set of prompts by a human tutor in the spirit of Socratic dialogue.

We selected the small topic of the HSB colour space as our first target for several reasons. We needed something conveniently limited for our initial work, partly in order to try out our overall strategy. Secondly, several studies (Winn, 1997; Salzman et al. 1996) have shown that 3D virtual environments are particularly appropriate for teaching complex and abstract concepts and since colour space has an inherently three-dimensional nature, this could offer a significant advantage. Finally, as we shall see, it turns out that surprisingly few people, even those who have worked with colour, are in fact familiar with this conceptualisation.

Our intention was also to implement the philosophy of Socratic dialogue in order to encourage externalisation of prior ideas and to create time for reflection. The main assumption of Socratic dialogue is that the learner already has the knowledge, or at least the necessary component elements, to answer the question. It is the task of the questioner to foreground issues relevant to the activity, which may not currently be the focus of the learner's attention.

Some art and design teachers argue that digital instruction happens too fast without allowing time for reflection or questioning (Smedal & Jacobsen, 2005). Choosing, picking and applying a colour with the mouse pointer on a computer screen cannot be compared with using paints to create colour samples. After experiencing the task once or twice the process becomes automatic and somehow subconscious. Hence, digital learning environments must be based on innovative teaching methods and tasks that lead to deep understanding of the subject by being motivating and enjoyable, but above all by promoting reflection within the learner's activity.

This evolved into our design for effective teaching, satisfying the theoretical criteria discussed above, and containing a balance of theory (the concept of three-dimensional colour space as Munsell’s tree and Runge’s sphere) and practical experience (arranging and placing colour samples in relation to each other). However, it was also valuable as a research method, because it gave prolonged opportunities for observing how participants arranged colours, the reasons they gave for their actions, and what this revealed about the different ways people think of colour. We report on this in the next section.

The method we used was to sit participants down in front of a table and take them through a sequence of tasks. A typical task would be to give them a pile of coloured squares (for instance 10 samples ranging from white through pink to fully saturated red) and a request (for instance "please arrange these in any way you think right") and after they completed it, to ask them why they chose the arrangement they did. They would then be asked a few other probe questions: e.g. where they would now insert one or two more squares (handed to them) in their current arrangements. The sequence of tasks was generally:

- Arrange a set of squares coloured white through grey to black.
- Arrange a set of squares coloured white through pink to red.
- Arrange a set of squares coloured black through dark red to red.
- Combine the two previous sets (white-black, red-black) of squares into a single scheme.
- Combine all three sets (white-black, red-black, red-white).
- Arrange a set of squares of fully saturated hues.
- Combine these (the hues) with the red to white set.
- Combine these two sets with the red to black set.
- Combine these three sets with the black to white set.
- Next, a cardboard skeleton of a sphere, with the vertical axis already marked as the gradient from black to white, and with Velcro tabs on, was put on the table; and they were asked to attach all the squares they had on it.
- Finally a set of test questions might be asked, including pointing to where a new probe colour should be placed within the 3D sphere; and what shade of colour should correspond to a point within the sphere pointed to by the tutor.

The participants were given a number of prompt questions, contingent on their actions. This means that the amount of direct instruction that learners received was the minimum possible, allowing them to maximise learning for themselves. The prompts were:

- Why does colour X go in position Y and not position Z?
- Before with these same cards you organised them like A, and now you have them organised like B. Why is that?
- Why have you done it like that?

- Why is colour X at the end of the line? Does it make any difference which colour is at the end of the line?
- Can you think of any other way to arrange them which might solve that?
- If I gave you these additional colours, how would you arrange them now?

We also implemented an alternative digital way of presenting this, using 3D digital models built in the Maya 3D software package on a desktop computer to replace the material cardboard squares and sphere (but still with a human tutor presenting the tasks and asking probe questions) and tested this too on a set of participants.

a. The study

We compared learning using the cardboard material, the digital models and a text (compiled from passages from several textbooks). We also compared performance on immediate post-tests i.e. at the end of the learning phase, with performance on delayed post-tests i.e. about a week later. We used participants, about 50 in total, who were mostly but not all in their early twenties. Some had art and design backgrounds, others had not. All those given the computer models had current experience on using the software package, so that familiarity with the user interface conventions would not be an issue.

b. Observations

While the participants were performing the tasks, notes, photographs and some video were taken in order to record the process. The photographs are available for viewing at http://www.psy.gla.ac.uk/~steve/patera/

The first strong impression is that those performing the material version of the learning tasks found it enjoyable, and indeed absorbing. Even those who took over an hour to complete them all were surprised at how the time had passed and none showed any signs of fatigue or boredom. These participants often used the word “play”, while the ones who performed the digital version considered it more like a problem-solving task. None of this could be said of those with the textbook version.

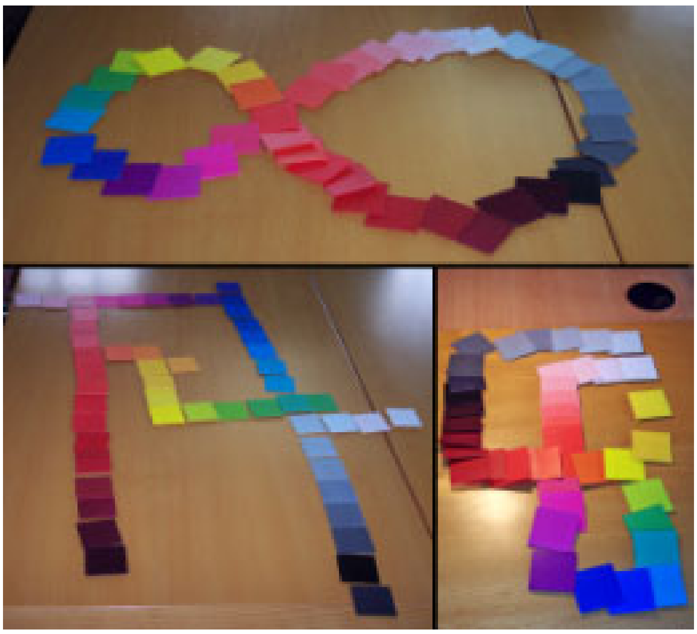

Figure 1. Various arrangements of the coloured tiles

Every person arranged the coloured tiles in a different way. As regards spatial relations, the patterns the participants formed varied from straight lines, circles and triangles to squares, spirals, stars and zigzag diagonal patterns (Figure 1). From the viewpoint of the concept we were trying to teach, we had the tacit view that for the black-white, red-black, and red-white sets a straight line was best, while for the hues a circle was better and combinations of these sets would require two or three dimensions. Particularly in early trials, the fact that our cardboard samples were themselves square in shape (whereas we could have made them circular, say) often seemed to influence people to use square or rectangular layouts. They also tended to reason in terms of the number of tiles in the current problem e.g. if there were nine, then a three by three square layout might be attractive. Increasing the number of samples and using probe questions that required them to add an extra tile or two to a completed layout tended to reduce this type of reasoning (which is demanded by some tests of spatial intelligence).

As regards the properties they were expressing in their spatial layouts, some participants were organising the colours according to their intensity or hue, while others were dividing them as cool and warm and many said they were arranging them by lightness, even in cases where the samples they were working on had been intended by us to show equal brightness, although limitations in the colour printing used to generate the tiles meant this was imperfect. Only a couple of them argued that colours should be randomly scattered and one claimed that colours are like music notes.

Watching participants' movement of tiles as they assembled a layout often made it clear how important placing samples side by side is for comparing small differences in colour. This can be done extremely rapidly and conveniently with cardboard tiles on a large tabletop: it seems an important feature to support in any computer implementation.

One of the reasons for developing the digital version was to provide the participants with the option to utilize the third dimension, which a flat tabletop might prevent them from considering. They were told at the beginning of the test that they were free to use all the views available in the software — orthographic and perspective — and switch between them. Yet, most "digital" participants performed the task using the top view and did not consider using the third dimension. Even when they were prompted to view their arrangement from a different perspective, most of them switched back again to two dimensions.

In the early development of our tutoring method, it emerged that the number of samples in a set was a significant issue. From the point of view of rapidly sorting samples on a given dimension, a small number seemed most convenient. However for getting learners to see a set as a smooth sequence of a single varying property, a powerful intervention or question was to offer another intermediate value and ask where it could be inserted into an arrangement. Introducing more and more fine distinctions seems important in dislodging people from the opposite tendency of seeing colour in terms of a small handful of landmark primary colours with no particular relationship to each other. This is in fact a form of a very general educational tactic that can be important in quite different areas, sometimes known as "bridging" (Brown & Clement, 1991; Brown & Clement, 1989; Brown, 1992) and which consists essentially of suggesting to the learner that they consider an intermediate case midway between two cases they regard as poles apart and unrelated, in order to see a connection between them.

The great variety of ways of arranging the squares, both spatially and in terms of the colour properties expressed, was true for both those from an Art school background and from a computing background. Initially we expected the educational and vocational background of the subjects to play a significant role on their performance. Almost half of the subjects had studied art and design, whether that was painting, sculpture, graphic design or product design. One might assume, since artists and designers apply colour extensively in their works, in the form of pigments or computer graphics, that they would have had a mental model of colour relations in their minds. Surprisingly enough, their performance did not differ from that of the other participants. It shows, however, that this kind of approach is effective at eliciting from each learner the properties of colour they are already aware of and which ideally they need to relate to any abstract theory or organising principle. This remains true even for conceptualisations, such as three-dimensional colour spaces, that they only express some properties of colour. In this case, a full appreciation of the theory should include a definite realisation of the properties it does not capture e.g. the cool/warm dimension or the emotional connotations of different colours, as well as the satisfactory integration of the properties it does address.

The majority of the participants did not have a clear mental model of how all possible colours could be related before the 3D sphere model was presented to them; however after arranging the tiles in each task, most of them provided good reasons to support their schemes. When the 3D sphere model was presented to them, most of them agreed that it related colours in a coherent way and tried to revise their conceptions. A literal interpretation of the notion of constructivism and of Socratic dialogue, is that each learner should construct the target concept for themselves, perhaps under the impact of experiences and questions arranged by the teacher. This was what we aimed for, but in most cases did not achieve in this version of the tutoring method. However, our impression from our observations is that this may not matter. The tasks together with our tutorial questions served first to get learners thinking of their own notions of colour, whether explicit or implicit, and to address the question of how to organise colours. They grasped, both practically and intellectually, that this is a problem that is not trivial, but which perhaps could be solved. This puts them in a position to appreciate what is good about a 3D colour-order system when it is offered to them. Their ability to place new test colours within the system shows that they grasped what they were seeing. In contrast, the texts we found describing the specific colour-order system do not say why it is good nor what the problem is that it actually solves. They do not prompt readers to discuss, for example, whether a cylinder would or would not be just as good as a sphere, why the axis rather than (say) a radius must progress from black to white, or where brown would fit in the sphere and what its neighbouring colours might be.

On the other hand, informal questions to the participants showed that they had not connected the technical terms "hue", "saturation" and "brightness" to the dimensions. This is not surprising since these are never mentioned in the version of the tutoring method tested so far, while they are of course mentioned in textbook treatments. However, this should be an easy improvement to make. It is also necessary if a full balance between practice and theory is to be achieved.

Digital versus material versions

As noted above, we tested both a computer based (digital) and a material (cardboard) version of our tutoring method. The preliminary data and the researchers' observations do not suggest any great difference in the effectiveness or enjoyableness between these two implementations. However, the digital version (once created) proved more flexible since it could be updated and altered much more rapidly and easily by a programmer than the cardboard materials. It is also portable and can run on most computer systems. The physical model needs a large carrier bag to carry around and it requires plenty of space, usually a big tabletop (about 1 by 1.5 meters), larger than most desks. After a number of tests, the cardboard began to bend and crush unlike the digital version, which of course does not wear out.

In the future we will explore making the digital version more autonomous i.e. explore automating the human tutor's role. This will require a) making the user interface readily usable by novices (in the trials, we used only participants already familiar with the controls of the software package): this is probably fairly easy. b) Building in the tutor's prompts. Since these were deliberately designed to be a standard set, this should be unproblematic. c) Automating the tutor's choice of which prompt to select. This will require the software to recognise features of the user's arrangement for each task (e.g. whether the squares were positioned into a straight line or a circle). This is more difficult. However our observations suggest that learners are not misled by inappropriate prompts, but simply benefit from those questions which are telling, so it is probably not hard to do this well enough to stimulate learning.

Participants reported enjoying “playing” with the cardboard squares because they could touch them. The tactile sense and the feeling of texture are important to some people. The computer screen is a single-sensory medium and it does not offer this experience, but more advanced technology can. Tactile feedback can be provided through hardware and software mechanisms incorporated within special gloves, which allow the user to interact with the virtual objects. Colour education might also be able to benefit from the use of such advanced 3D visualisation. Our aim is to take this study further by creating and evaluating a virtual 3D environment for teaching and learning colour theory.

Conclusion

Preliminary inspection of results from these early trials suggest that there is no great difference between digital and material implementations of our tutoring method and so that further development of digital versions is worthwhile to gain the advantages of robustness and ease of distribution. Participants seemed to retain their knowledge longer from our tutoring methods, than did those who were given a passage from a textbook on the same theory. This is consistent with our analysis based on educational theory. However, still more benefit may be obtainable if we are able to improve our tutoring method further in the light of our observations. The challenge is to refine it so that participants gain a still fuller appreciation of the concept of 3D colour spaces (a way of organising all possible colours into three dimensions) and what aspects of their ways of thinking it does not directly accommodate, even though they are valid, such as express divisions of colours into "warm" and "cool".

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