Coloring Inside the Lines: A Learning Strategy Using Coloring to Help Students Understand Orthographic Projections

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Abstract

We present a learning strategy developed for a freshman engineering graphics course, in an attempt to help students with low spatial visualization ability who struggle to mentally visualize 3D geometry from 2D orthographic multiviews. This method teaches students to "think on paper" to help clarify their mental thought process while they work on orthographic projection problems. Students make guesses about relationships between faces in different 2D views and then test their guesses by coloring in corresponding faces using colored pencils, as an adjunct to 3D pictorial sketching. This hypothesize-and-test method gives students a starting point for visual problems that they may otherwise struggle to begin. In this digest, we present the foundations of this method and share examples, illustrating the method's use.

Introduction

While students who are high visualizers tend to perform well in engineering graphics classes regardless of special intervention, low visualizers often need extra training to succeed. At some institutions, an additional class has been developed that is dedicated to improving the spatial visualization ability of low visualizers so that they can succeed in subsequent engineering graphics classes (Sorby, 2007; Hsi, Linn, & Bell, 1997; Metz et al., 2011). At University of California, Berkeley, no such separate class is currently offered, so there is a wide range of student spatial visualization ability in the freshmen-level engineering graphics class, E25: Visualization for Design. Low visualizers have been observed by instructors to need extra attention in office hours and in lab, especially when learning how to interpret orthographic multiview drawings and make pictorial sketches from them.

Because orthographic projections are a fundamental part of engineering graphics, this topic has been the focus of previous work on how to best teach it. Sorby (1999) notes that despite being such a challenging topic, multiview sketching is typically presented early in graphics textbooks, despite pedagogical research suggesting that students might learn such an abstract task more easily if they started with a more concrete task, namely sketching objects actually in front of them. This would allow students to gain skills in pictorial sketching before multiviews are first introduced (Sorby, 1999). In this digest, we describe pedagogical strategy that uses coloring of faces as a way to build students' logical reasoning while sketching.

Background

In our class, following the Lieu and Sorby textbook (2017), we begin with visualization exercises where students sketch isometric pictorials from coded plans, before the introduction of multiviews. We organize the topics so that students first solve simple problems and then work up to solving more complex problems by building on the skills for solving the simple problems. In terms of geometric complexity, our first multiview exercises ask students to sketch multiviews from pictorials of objects with only axis-aligned faces. Then we introduce examples with inclined and oblique faces. To prepare students for interpreting multiviews, we explicitly enumerate these three categories of face orientations and describe the characteristics of each that are relevant for identifying matching faces in multiviews. Then students practice with multiview face-matching exercises, where they write down the labels on faces in one view that correspond to faces and edges in an adjacent view, with or without a corresponding isometric pictorial for reference (see Bertoline and Wiebe (Chapter 10, 2009) and Lieu and Sorby (Chapter 11, 2009; supplemental material, 2017)). Finally students move on to pictorial sketching from multiviews.

However, we have observed that students are often at a loss about how to begin when trying to make an isometric pictorial sketch from a challenging multiview drawing that they cannot holistically visualize. For low visualizers this will occur even with relatively simple examples, but many other students encounter the same phenomenon of not knowing how to start (or getting stuck part way through with no idea about what to try next) the first time they encounter a model for which they do not have a full 3D understanding/interpretation of the geometry.

One possibility for why students get stuck is they may believe that their approach to interpreting the simpler multiview interpretation problems *should* form the basis for solving the more challenging multiview problems. For the simplest geometries, our students probably could visualize the entire 3D shape in their mind, and then sketch from their mental visualization. Therefore it seems possible that students moving from simpler multiview interpretation problems (that they can visualize directly in their mind) to more complex problems (that they cannot) may intuitively be trying to build upon the expertise they have acquired in solving the simpler problems; however the visualization skills that they have previously mastered aren't sufficient in this context. Beyond the issue of getting stuck on how to start or continue a sketch, when students make sketching mistakes, they often don't recognize them when they occur. One common mistake is that they have sketched a face in 3D space that is consistent with one of the given orthographic views, but not with either of the two adjacent views of the face. Another common mistake is that one 3D face of their sketch might be consistent with the assumption that face A in the front view corresponded to face 1 in the right view, but then another face of their sketch was only consistent with face A corresponding to face 2. Such mistakes may indicate that students have difficulty keeping track of how they are resolving faces in different views or which faces in the multiviews they have already resolved in their sketches.

Implementation

During office hours, Prof. McMains' first goal is to determine what in the student's thinking process led them astray, why they got stuck, etc. Asking students about which multiview faces corresponded to which faces they are sketching is very useful in this regard, but if they do not make these intermediate steps visible, it is challenging to help them see their own mistakes. Even though we had just assigned face matching exercises, students would not seem to think to use this strategy as an intermediate step when making an isometric sketch from a multiview. Having them label faces and then list which faces matched up wasn't a convenient reference to be consulting as they sketched. Prof. McMains first turned to having the students use colored pencils to color in the hypothesized matching faces in office hours so that *she* could see what they were thinking, but it was clear almost immediately that coloring also helped make *the students themselves* aware of their own thinking. This was so effective that now we require all students to purchase colored pencils.

The technique is introduced in lecture, using the same color to indicate the matching faces in all three typical views in a 3-view drawing and showing the corresponding colored faces on a pictorial (Figure 1a). This was inspired by Bertoline et al.'s example of using different colors for each face for a more complicated geometry in their textbook (2009). However, in order to better help students track correspondences, in addition to coloring faces that appear in face view, Prof. McMains also colors the corresponding edge when a face appears in edge view so that each color shows up exactly once in each view (Figure 1b).

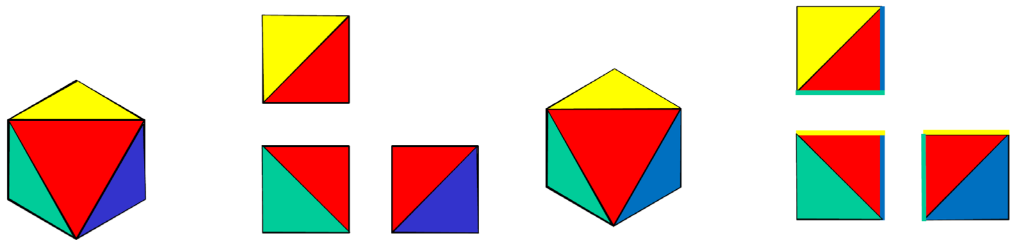
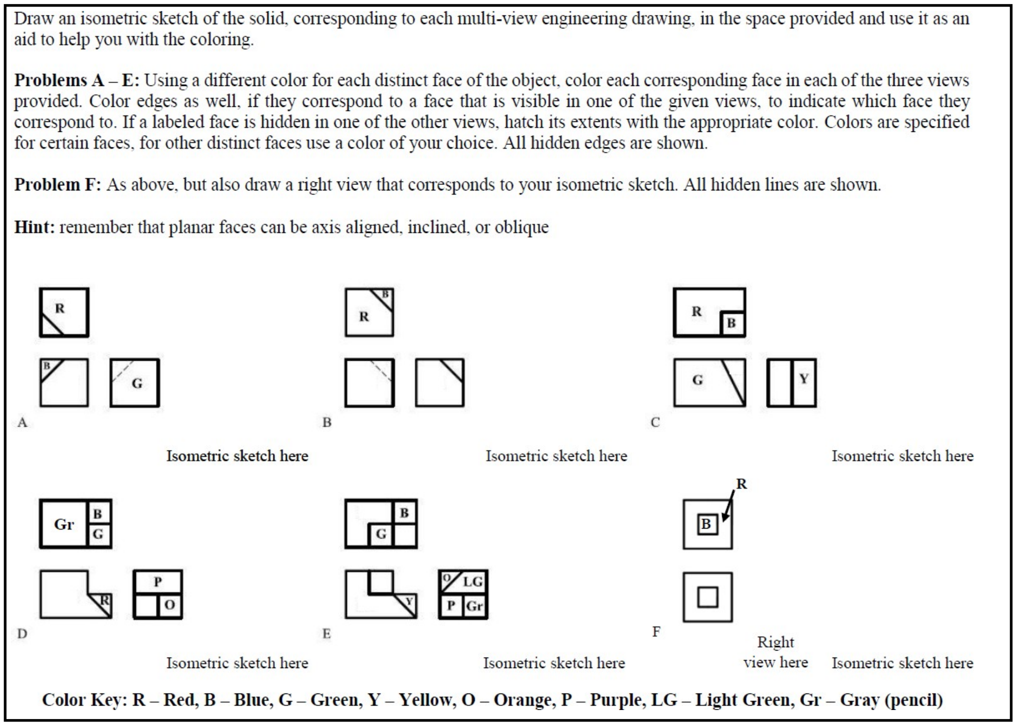


Figure 1. a) Color match for visible faces. b) Color match including edge view faces.

Next, similar to “mentored sketching” demonstrations during lecture (Mohler & Miller, 2008), but extending the technique to “mentored coloring” as well, the professor demonstrates how to use coloring to keep track of hypothesized face matches when solving a simple Multiview sketching problem, projecting the coloring and sketching process with a document camera while talking through her reasoning. Choosing one view to start, she first colors each visible face a different color. Choosing one of these as the starting face (what Lieu and Sorby call the anchor surface (p.11-34, 2009)), she describes how she makes an initial hypothesis about which face in an adjacent (2nd) view it might match up to, coloring it in to match. Then she describes how she tests the hypothesis for consistency while finding and coloring the corresponding matching face in the 3rd view, assuming there is such a consistent match. If not, the hypothesis coloring in the 2nd view is erased, and a different hypothesis is colored in instead and tested in the 3rd view until a consistent match is found. Next the 3D position is sketched in the isometric. The back-and-forth, hypothesize-and-test nature of the problem solving is emphasized, as this process is repeated for other faces with other colors.

In lab, students practice the technique with a coloring worksheet (Figure 2). The instructors walk around to prompt students who are having difficulty starting a problem to just make a hypothesis, color it, and see where it leads, telling them that pencil can easily be erased. Another category of students have difficulty because they just start making random coloring guesses in all views without testing each hypothesis in turn. Both the hypothesize step and the test step need to be emphasized as equally important.


Draw an isometric sketch of the solid, corresponding to each multi-view engineering drawing, in the space provided and use it as an aid to help you with the coloring.

Problems A – E: Using a different color for each distinct face of the object, color each corresponding face in each of the three views provided. Color edges as well, if they correspond to a face that is visible in one of the given views, to indicate which face they correspond to. If a labeled face is hidden in one of the other views, hatch its extents with the appropriate color. Colors are specified for certain faces, for other distinct faces use a color of your choice. All hidden edges are shown.

Problem F: As above, but also draw a right view that corresponds to your isometric sketch. All hidden lines are shown.

Hint: remember that planar faces can be axis aligned, inclined, or oblique

Color Key: R – Red, B – Blue, G – Green, Y – Yellow, O – Orange, P – Purple, LG – Light Green, Gr – Gray (pencil)

Figure 2. Lab coloring worksheet.

Discussion

Implementing this strategy has been very successful at reducing the number of students who get Ds and Fs in the class. Before, there would be a number of students in a large class who did very poorly on midterm or final exam problems that involved challenging multiview interpretation, drawing very little beyond perhaps a bounding box, or reproducing the given views on the sides of such a box. On the midterm we now require the students to bring their colored pencils and color in the hypothesized matching faces, which seems to help them then with their isometric sketching. For students who can visualize and sketch without first coloring, they can just color matching faces afterwards to check their work. We will examine the effectiveness of the hypothesize-and-test coloring strategy as a teaching method more extensively in future work.

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