Using a problem-solving heuristic to teach engineering graphics

Shari J. Kimmel[a], Fadi P. Deek[b] (corresponding author) and Howard S. Kimmel[b]
[a] *Department of Mechanical Engineering and Mechanics, Lehigh University, Bethlehem, PA 18015-3085, USA*
[b] *New Jersey Institute of Technology, Newark, NJ 07102, USA*
E-mail: Fadi.Deek@NJIT.edw

Abstract Students often experience difficulties in developing an adequate understanding of how to solve engineering graphics problems using traditional teaching methods. Application of an explicit problem-solving technique to graphics problems can help students to understand the solution strategy. This method reinforces the details of the process, enabling students to apply the same techniques to more complicated problems. The problem-solving heuristic involves devising and evaluating a solution plan before it is implemented. Without such a solution plan, students are more likely to rush into an ill-conceived solution design without any meaningful preliminary thought. By considering a detailed solution plan for even simple problems, students should gain an in-depth understanding of the class material. This paper presents and discusses the implementation of a problem-solving approach to engineering graphics, which can be applied to both drafting and computer-aided design (CAD) exercises. Preliminary results indicate that students' skills at solving engineering graphics problems improve as a result of implementing a structured approach towards developing a solution plan.

Keywords problem-solving heuristic; engineering graphics; computer-aided design

Introduction

The introductory class in many engineering programs covers principles of engineering graphics [1] and introduces engineering design. Though problem solving is considered an important aspect of the design process, it is often perceived as an abstract concept which is difficult to teach and assess. However, a problem-solving heuristic, which has proven successful in helping students learn to evaluate and solve computer programming problems [2], has been extended to help students understand and evaluate engineering design problems [3]. In engineering graphics and design textbooks, problem solving is typically mentioned only in introductory chapters about design; however, students should be able to apply relevant parts of this method to graphics problems in order to better understand how these types of problems are solved.

The engineering design and graphics course (ED&G 100) at Penn State Berks–Lehigh Valley College exposes beginning engineering students to conventional drafting techniques, computer graphics and engineering design. The typical class consists of mostly first-year with a few second-year students and spans a wide range of previous experience in engineering graphics. Throughout the fall 2000 semester, a class of 17 students, which was taught by the first author, included integrated problem-solving exercises in different aspects of the course.

Since students come from a variety of backgrounds, some had significant drafting experience during high school, while others had none at all. Towards the end of the graphics component of the course, most students had mastered the basic principles of orthographic projections, but several students did not demonstrate adequate knowledge of even basic principles. These students were able to determine solutions to simple problems during class when they could consult with each other an obtain help from the instructor. However, they were not able to explain why they would attempt a particular solution to the problem presented, had difficulty solving problems by themselves on a test and could not solve more complex problems. By utilizing a solution plan and design, students would learn the detailed steps required in the solution process and be able to apply these steps to a variety of problems. Preliminary studies show that this method could help students learn how to apply basic techniques and, hopefully, gain a better understanding of solving these types of problems.

This paper will first discuss the problem-solving heuristic in general. Then, implementation of this method in an ED&G 100 section during the fall 2000 semester is explained for engineering graphics and solid modeling problems. To examine the effectiveness of these problem-solving exercises, the ability of these students to solve graphics problems is compared with that of a section that was not exposed to extra problem-solving exercises. Finally, some ideas for improving the application of this problem-solving heuristic to engineering graphics exercises in the future are presented.

Methodology

A problem-solving heuristic, used very successfully in introductory computer science classes at the New Jersey Institute of Technology (NJIT) [2], can be adapted to the needs of engineering students. The heuristic consists of five stages: formulating the problem, planning the solution, designing the solution, testing the solution, and delivering the solution. These stages are based on a four-step method proposed by George Polya in 1945 [4]. Formulating the problem involves developing a well defined description of the problem statement. In planning the solution, alternative solutions are examined. Then the problem is decomposed into subproblems, and all relevant parameters from the original problem description are associated with each subproblem. In the third stage, designing the solution, the description of each subproblem is refined, and further decomposition is performed, and a plan for solving each of the subproblems is identified. Next, in the solution-testing stage, the solution plan is carried out, and the results are analyzed for correctness, reliability and efficiency. Finally, during solution delivery, the solution and any other necessary information are organized, documented and presented for future reference. At any point in the process, modifications to previous steps may be made. For instance, the solution-testing step often shows that modifications are needed in the solution planning, design, or problem formulation. This problem evaluation and feedback is an essential step in realizing an acceptable solution.

In engineering graphics, unlike engineering design problems, the problems is often well defined. However, students greatly benefit by applying the other steps, especially solution planning, design and testing, to graphics problems, such as orthographic projections. In practice, students resist using a problem-solving heuristic. In particular, the responsiveness of the computer seems to encourage students to attempt a solution without having a well thought-out plan. Therefore, any solution planning prior to implementation of a solution assists students in completing an assignment. Instead of requiring students to use the formal problem-solving heuristic, an informal methodology, which should be less intimidating to students, is encouraged. Students are simply instructed to clearly define the problem and describe their solution method verbally. When students are sufficiently motivated to apply this type of methodology, they produce more accurate solutions. In addition, the instructor can more easily resolve student misunderstandings. Students are encouraged to use their own creativity when implementing this problem-solving heuristic, so that this type of assignment would hopefully appeal to all students, not only those who prefer learning styles addressed by standard teaching methods [5].

Implementation

In the drafting component of the course, the students are expected to learn how to solve orthographic projection problems. These problems involve an incomplete three-view drawing of an object (top, front and right-side views, typically), and the student must draw either one missing view or missing lines on one or more views. Often a three-dimensional representation of the object is not given in the problem statement. Each feature of the object is usually uniquely defined in two of the views, requiring students to examine aspects of both these views and correctly use the information to draw the third view. At the beginning of the semester, the problem-solving component is introduced by attempting to have the students evaluate and describe each individual step as they work on the problem. Ideally, they use their written solution to make sure the three drawings are consistent and, thereby, verify their answer.

Initially, students found the process too tedious, time consuming, and not very useful. Some students either already knew or learned enough of the basics to give answers that appeared to be good enough on almost all problems, so they were not motivated to apply a problem-solving procedure. Those students who had more difficulty solving these types of problems were not able to explain the steps in their solution method, even for those steps performed correctly. By describing verbally how they work out the simpler problems at the beginning of the semester, students should be able to learn why they should draw lines in particular locations and, therefore, better understand the method involved in solving these types of problems.

To test these ideas, the students were offered an extra credit opportunity after their final drafting test. First, they were given the homework assignment shown in Fig. 1 and the solution method in Fig. 2 to give them an example of a (partial) structured written solution plan and to show how it could help them obtain the correct solution. Fig. 2 is an example of one type of written solution, and most students followed this example rather than changing it to fit their individual styles. Then, a week later, for extra credit points on their test grades, they were given two orthographic projection problems to work on during class time. In order to obtain partial extra credit points, they were required to provide a written solution. Though extra credit

Problem statement: Sketch the top view. The front and side views are complete. In addition, write down the steps that are required to solve the problem.

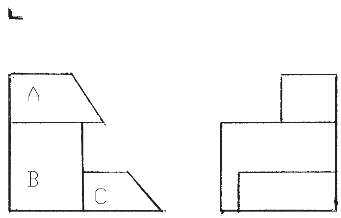


Fig. 1 *An orthographic problem given in the class.*

points on the quiz were thought to provide enough motivation to persuade most of the students to attempt the problems, only seven students actually started working on these problems. Of those seven students, two gave up after 5 or 10 minutes, two turned in only their answers, and the remaining three students did turn in answers with written solutions.

The written solutions to these extra credit problems demonstrate an increase in a few students' understanding of the solution of orthographic projection problems. As an example, the solutions to the two extra credit problems turned in by the student who received the lowest grade on the test are shown in Fig. 3. In an attempt to improve poor test grades, this student was motivated to try the problem-solving methodology. The student's solution to first problem, shown in Fig. 3a, is almost correct, which is probably a result of the written plan provided by the student. This solution demonstrates a greater understanding of orthographic projections than the student's answers on the test. For the second problem (Fig. 3b), the written plan is much sketchier, and, as a result, the student's solution to the first problem is closer to the correct answer than the solution to this problem. In addition, as a result of the student's written solution design, the instructor can more easily help the student understand mistakes, and, therefore, correct them in the future. For instance, in Fig. 3a, the student can be shown that point R, as labeled by the student, is not consistent between the front and the top views, and that discrepancy directly led to the student's error in the problem solution. In Fig. 3b, the labels placed on the drawing by the student can be helpful when trying to visualize the three-dimensional object. Point C can be used to illustrate why the horizontal line drawn by the student in the lower half of the side view does not extend across the entire object. This brief exercise indicates that convincing students to evaluate and verbalize solution steps to a problem could prove to be a beneficial learning technique.

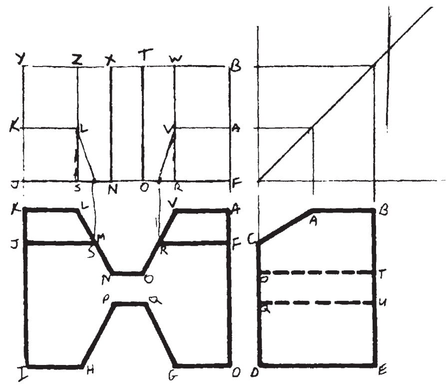
For this exercise, you will be provided with many of the steps needed to solve the problem. Follow them to begin your solution of the given orthographic projection. Then finish the drawing and continue writing down the steps as you solve the problem.

1. Observe that the front and side views are given. The problem involves projecting each of these shapes to the top view.
   a. The height and width of each shape are given in the front view.
   b. The height and depth of each shape are given in the side view.
   c. We need the width and depth of each shape in the top view.
   d. Therefore, we need to take information from both given views to draw the top view.
2. Draw a miter line.
3. Draw shape A.
   a. Project the width of shape A from the front view to the top view using light construction lines. We don't know yet the depth of A, so the width of A should be represented as light vertical construction lines.
   b. Project the depth of shape A from the side view to the top view using light construction lines.
   c. Label the four points in the front view of shape A
   d. Find the corresponding points in the side view of shape A and label them (some points in the side view probably two one labels).
   e. Locate the corresponding points in the top view of shape A and label them. Connect them in a way that is consistent with the front and side views.
   f. Notice that the front view of shape A has a corner. Since this corner can not be seen on the side view, it must appear as a ________________ line in the top view.
   g. Notice that shape A is on the top, so all the lines are visible.
3. Draw shape B.
   a. Project the width of shape B from the front view to the top view using light construction lines.
   b. Project the depth of shape B from the side view to the top view using light construction lines.
   c. Label the four points in the front view of shape B
   d. Find the corresponding points in the side view of shape B and label them (some points in the side view probably two one labels).
   e. Locate the corresponding points in the top view of shape B and label them. Connect them in a way that is consistent with the front and side views.
   f. Notice that shape B is below shape A. Therefore, any lines from shape B that are below shape A must be hidden.
4. Draw shape C.

Fig. 2 *An example of one type of a partially completed written solution.*

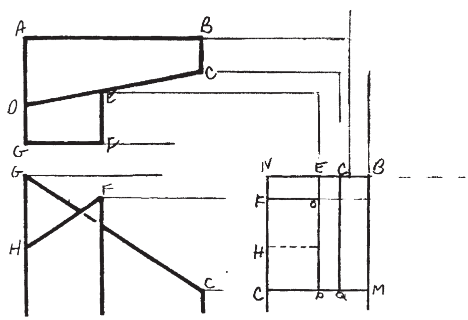
A similar exercise was presented to a second section of this course, who did not have any prior problem-solving exercises. These students were also given the problem in Fig. 1 and the partial sample solution in Fig. 2; the problem was completed during class time as an introduction to this type of problem-solving method. Then they were given another orthographic projection problem and asked to think about and write a solution plan for it. Most students tried to find a solution to the problem and then verbalized the steps. Some students were able to solve this problem correctly. However, many students worded out an incorrect answer and then complained about having to provide the written information about the solution steps, with comments such as 'Is this a problem?', 'This is not the way I do the problem',

a)



1) Extend lines of front view to the top view
2) Find distance between front & side views are portray the[m] in the top view
3) Draw miter line
4) Project point A in the side view to the top view
5) Project point B in the side view to the top view
6) Label the points in all 3 views

b)



1) Extend lines in front view to side view
2) Make a miter line
3) Portray top view to side view
4) Label points in all 3 views

Fig. 3 *The solution provided by the student with the lowest grade on the rest to two orthographic projection problems using an informal problem-solving methodology.*

and 'This is verbal, and I am a visual thinker'. In reference to the last comment, they had been instructed that Fig. 2 is one example of an adequate solution but that they could use any other method they chose. One or two students used the information given to sketch a three-dimensional representation of the object, which was used to produce an answer to the problem. Two typical student solutions from this class are shown in Fig. 4. These solutions do not contain the same specific infor-

a)

1) Construct mitre [sic] line
2) Transfer depth lines from view 2 to construction line
3) Draw overall shapes of object in top view
4) Transfer width lines from view 1 to top view, being sure to run lines all the way through object in top view
5) Draw arc by connecting all points that transferred from two views
6) Transfer lines from square cut out from view 2 to construction line
7) Transfer lines from view 1 to top view to show placement of square cut out
8) After front face is drawn, draw needed hidden lines
9) Erase all unneeded construction lines

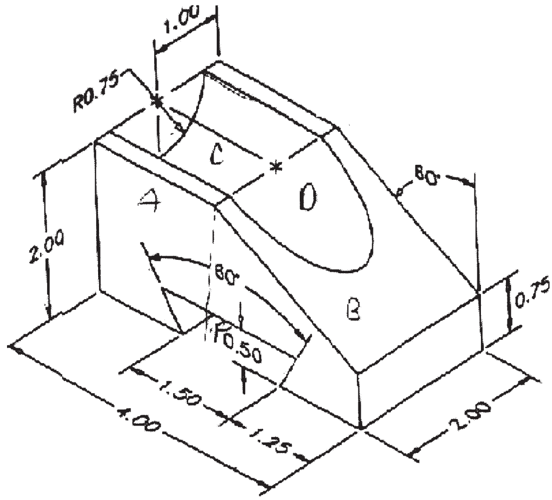
b)

a) Draw a miter line
b) Project points of cut section in the bottom of object. Draw visible and hidden lines for it.
c) Project points along the curve into top and side views.
d) Cross reference corresponding points in side view onto the miter line. Then project them onto the curve in the top view.
e) Sketch the curve in the top view using the points that were found.

Fig. 4 *Examples of solutions to an orthographic projection problem by students in the control class.*

mation about constructing the solution and references to specific points on the drawing that are found in Fig. 3a. In addition, since these students did not label any points in the original drawing, clearing up any misunderstandings would be more difficult. On the other hand, the detailed solution plan in Fig. 3a demonstrates an understanding of the basic method used to solve the problem. A student who can produce such a plan should do better on a test than a student who cannot, though a more complete study still needs to be done to better determine the value to the student of these problem-solving exercises.

Since splitting up a larger problem into smaller subproblems is the essence of creating solid models, students were asked to provide a written solution design for several solid modeling assignments before implementing them on the computer [3]. By separating the solution procedure from the implementation in AutoCAD, students could concentrate on the problem-solving aspect of the assignment before worrying about exact AutoCAD commands and syntax. Three-quarters of the students mentioned that this procedure was helpful, while less than one-quarter found it a waste of time. Both sections of this class were then given the same solid modeling problem, and the students were asked to provide a written solution to the problem. Every student in the section which included problem-solving exercises was able to develop a solution design in which each step could be readily translated into an AutoCAD command, as shown in Figs 5 and 6. Several students in each section gave the simplest solution to the problem, but the sample solutions shown here are from students who were not near the top of the class.



1. Solid Model
   A. Box
      1.) UCS
         a.) world
   B. wedge
      1.) UCS
         a.) World
   C.) Circle
      1.) Change UCS
      2.) Inside part of box
      3.) Extrude out till it meets the wedge
   D.) Ellipse
      2.) Inside part of wedge
   E.) Trim
      1.) make C (circle) halt
      2.) make D (ellipse) halt
   F.) triangle
      1.) change UCS so that triangle is upside down
      2.) make triangle on side of box and wedge

Fig. 5 *Solution to the solid modeling problem on the quiz, by the same student as in Fig. 3. Isometric figure from Leach [8].*

These written solution plans help to differentiate between difficulties in the logic behind the solution and using the correct AutoCAD command with the correct syntax. For instance, in Fig. 5, the student refers to a ‘triangle’ and the command ‘trim’, which are two-dimensional commands and would not be applicable to a three-dimensional solid model. This type of exercise indicates that the instructor needs to review the difference between the ‘trim’ command and Boolean operators. Two other student solutions are shown in Fig. 6. Not only are these solutions reasonably

a) I would first start by drawing the side I labled [sic] (a). I would then extrude that to two inches. I would then change the UCS so I could work with the sideview of the object. I wouled [sic] draw a cylinder with its center lined up with the top of the alread[sic] drawn object~~. I would join the cylinder and the object.~~ Finally I would subtract the cylinder and the final product would be created.

b) I cut up the above object into objects which are easier to develop in 3d.
- To build the base I would start with the world coordinate and construct a rectagle [sic].
- To construct the cut out I would put in the stated coordinates and draw the object in onto the rectagle [sic]. To give it depth I would extrude the object back a distance of 2.
- The next solid object would be the square in the back. I would construct this on top of the rectagle [sic].
- I would then construct the triangle at the right of the object.
- The basic object is now there except for the cylinder on top.
- I would need to change the coordinate system by electing and saving my own coordinate system on the top of the object.
- I would click on the solid cylinder icon. Give the correct dimensions and slice the object in half.
- Union the 3 solid objects on the bottom
- Subtract the cylinder with the solid bottom.

The object is complete

Fig. 6 *Two additional student solutions to the solid modeling problem.*

detailed, but students also have given a reason for doing many of the steps, which shows a greater degree of understanding. For instance, in Fig. 6, the students says 'To build the base', demonstrating that the student is able to divide the problem into subproblems and tackle each subproblem.

In the second section of this course, most of the student solution plans were not as easily translated into AutoCAD commands, because their solutions skipped steps or contained steps that corresponded to several solid modeling commands, as shown in Fig. 7. The students in this section were less likely to give specific numbers in their solution plan and instead to use vague phrases, such as 'observed dimensions' (Fig. 7b). In addition, statements such as 'Draw a small box under the larger and subtract it' (Fig. 7a) and 'subtract wedge from bottom of object' (Fig. 7b) will not give the desired result if directly implemented in AutoCAD. With some practice, these students would probably produce as detailed a solution as students in the first section. However, the creation of the more detailed solution plan should enable the student to more effectively solve a problem. This conclusion is especially supported by the student example in Fig. 3, though a more thorough study is needed.

Discussion and recommendations

To address the students' reluctance to spend time applying the problem-solving heuristic, a guided instructional approach, such as that suggested by Woods *et al.*

a)

a) Draw a box 2 high 4 wide 2 deep
b) Draw a cylinder through the top of the box and subtract it
c) Draw a small box under the larger box and subtract it
d) Draw the small wedges adjacent to the subtracted box and also subtract those

b)

1) draw rectangle as a base
2) extrude to height
3) subtract wedge from bottom of object using observed dimensions
4) subtract wedge from top to make an incline in the front using the observed dimensions
5) subtract cylinder from top using observed dimensions.

Fig. 7 *Solutions to solid modeling problem by students in the control class.*

Consider the projection of block A in the top view.

1. Which dimensions of block A are represented in the top view? *width and depth*

2. Which view shows the width of block A? *front* Project the width onto the top view.

3. Which view shows the depth of block A? *side* Project the depth onto the top view.

4. Does block A have any interior features which are visible on the top view? *yes, the line between the horizontal surface and the sloped surface* What does the front view tell us about the location of the feature? *It tells us the distance between the left side of the edge of the block and the beginning of the sloped surface.* What does the side view tells us about the location of the feature? *It tells us that the sloped surface extends across the entire depth of block A.*

Fig. 8 *Example of a worksheet using the guided instructional approach to help students develop a solution design for the problem in Fig. 1. The intended answers are shown in italics.*

[6], could be implemented. In the design component of the course, a guided instructional approach assisted students in formulating the problem statement [7]. Without the guided instructional approach, students gave a very vague description of the problem statement, such as 'The cart is unsafe'. With the guided instructional approach, students gave a more specific description of the problem statement, with responses such as 'The cart tips easily'. The latter response gives a more specific indication of the problem to be solved, and, therefore, helps identify a solution.

For example, at the beginning of the drafting lessons, students would be given a worksheet to accompany even simple orthographic projection problems, with questions such as, 'Explain how you chose the distance between vertical lines A and B in the top view. Refer to labeled points and/or lines in the front or side view in your answer'. An example of a part of a worksheet which could accompany Fig. 1 when using a guided instructional approach is shown in Fig. 8. These types of questions would require students to explain the solution method they are using without going through the effort of a detailed written solution from scratch. If they can explain how they solve a particular problem, they are more likely to be able apply the method to other problems. These solution plans could also assist the instructor in addressing misunderstandings that exist and reinforce the solution method so that the students are more likely to have a better understanding of the material.

By applying this method from the beginning of the semester, students would have more practice verbalizing a solution plan, which would help them become more capable problem solvers. Ideally, they would be able to easily apply the same principles to different types of problems, such as the drawing of auxiliary views, without any difficulty. In this class, the students perceived auxiliary views as a different type of problem and did not immediately understand how to apply the basic principles of orthographic projections to this new type of problem. If this problem-solving method had been presented very early in the course, one test of its success would be to see if students could apply the same basic principles to new problems.

Summary

A problem-solving methodology which helps students understand and solve engineering graphics problems was presented. This technique has had some preliminary testing in the classroom using orthographic projection and solid modeling problems. Although this method needs to be tested with a much larger group of students, initial results, as demonstrated by several student examples, show that students who have been exposed to this problem-solving methodology are able to provide a clearer solution plan to these types of graphics problems. In addition, a descriptive written solution seems to help students provide a correct answer to the problem. Most students said that they found these exercises helpful for completing the assignments. However, they were also resistant to the additional effort involved in the preliminary solution-planning steps.

To improve the implementation of the problem-solving methodology, an informal problem-solving technique should be introduced at the beginning of the course. Perhaps a worksheet that uses a guided instructional approach and accompanies assigned problems would encourage students to evaluate the solution plan they use to solve the problem. After considering a solution plan for just a few assignments, students would hopefully have a better understanding of how and why they perform each step in their solution procedure, and they would be able to utilize the same techniques for a variety of problems.

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