Developing a Method to Quantify Difficulty of Engineering Graphics Assignments

Rahul Sharan Renu and Brett Shields
Francis Marion University

Abstract

Three dimensional solid modeling is often taught using software which use Boundary Representations. The goal of this work is to use Boundary Representation information to create a system which generates Engineering Graphics assignments. Specifically, this research addresses assignments where students are tasked with re-creating a solid model. In this research, model information such as number of faces, number of loops, number of edges, edge dimensions, and number of vertices is used to develop a model of assignment difficulty. This difficulty metric is used to retrieve assignments from a database for student practice.

Keywords

Solid modeling assignment; CAD models; Machine learning; Engineering graphics education

Frame of Reference

Scope of Work: Engineering Graphics Assignments under Consideration

The focus of this research is on engineering graphics assignments where students are required to (re)create three-dimensional solid model part files using parametric solid modelling. The most common way of communicating expectations to students is by providing them orthographic views of a specific part and requiring them to recreate the part in a three dimensional environment (see Figure 1).

These types of assignments can be perceived as difficult for two reasons. First, students may have trouble interpreting the two-dimensional orthographic projections and understanding expectations. Second, students may interpret the orthographic projections with no issue, but may have trouble modelling the three-dimensional part. This work aims to develop a method of ranking a three-dimensional solid model's difficulty regardless of the source.

Engineering Graphics Education

Engineering graphics has several components including two-dimensional sketching, two-dimensional orthographic projections, three-dimensional solid modelling of individual parts, three-dimensional modelling of assemblies of parts, and conversion between three-dimensional models and two-dimensional orthographic projections. To be well-versed in engineering graphics, it is imperative for students to learn/develop spatial visualization skills[1–3]. Previous researchers have found that development of spatial visualization skills is particularly challenging for students[4–7].

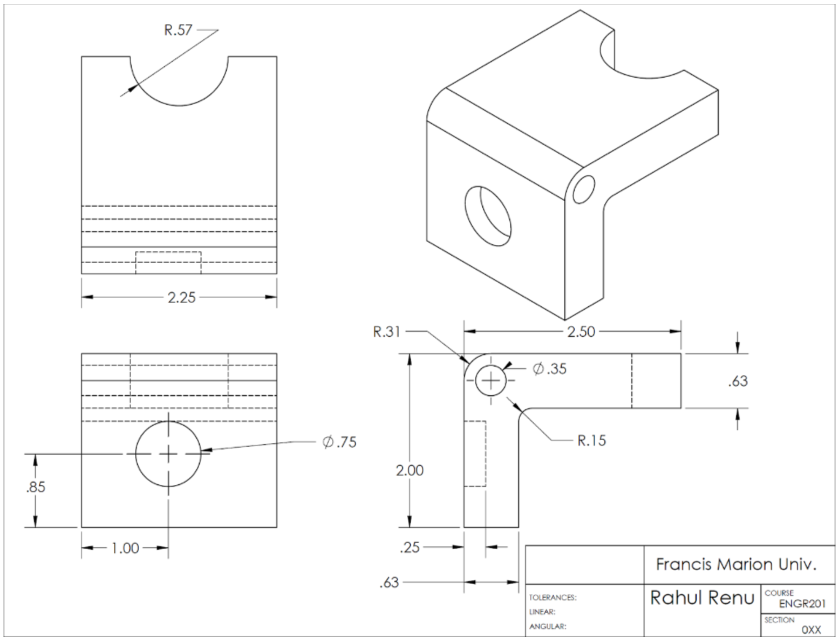


Figure 1: Example Assignment for an Engineering Graphics Course

This challenge is enhanced by the fact that engineering graphics is typically a first-year course for most engineering majors [1,8,9]. In most cases, this implies large-enrollment classes where instructors are not able to provide individual attention to all students. In other cases, when instructors are able to provide individual attention, students may learn at a different pace. Either way, there is a need to ensure students have ample practice opportunities [1,7,8,10]. To this end, the goal of this work is to develop a method to quantify the difficulty of a solid model from the standpoint of engineering graphics education. This model can be used by instructors to ensure that engineering graphics assignments are of an appropriate difficulty.

Designing Assignments (Designing Problems for Student Practice)

Designing assignments can be a difficult task. It is imperative that assignments are designed so that the student is challenged at an appropriate level[11]. The design can have a direct impact on the student's ability and motivation to learn[12]. If a problem that is challenging is presented to a novice, the learning experience may be hindered. Likewise, it does not seem beneficial to provide advanced students with introductory level problem sets. Ideally all student would progress through the course at the same pace, yet this does not always seem to be the case in practice. Because students have various learning experiences, styles, and backgrounds, providing a uniform set of practice problems may not be ideal. A better approach is proposed that can assist in the design of student's practice problems in a diverse setting. It may be beneficial for a more specialized delivery of problem sets to the students.

With the proposed system for assessing model difficulty, any number of solid models can be input into the system and the models can be properly classified. This automation can provide a useful tool in providing a customized set of practice problems based on the instructors knowledge of the student's level of proficiency.

Methods of Assessing Solid Model Difficulty

Several metrics relating to the difficulty of a solid model can be used for this research. In this section, a discussion of each metric along with its suitability to compute difficulty is discussed.

First, time required to make a solid model could be used as a metric of difficulty. Time can be obtained in two ways: computationally from the metadata of a solid model file, and by observing modellers. The former is a challenging method to obtain time required since modellers may take breaks, or may become distracted, while modelling a part. This will result in solid modelling software reporting inflated times required to make a solid model. The latter (i.e. human observation), apart from being a time-consuming process, is an intrusive method of data collection. The act of observation itself may lead to modellers taking unusual amounts of time to model a part. Therefore, time to model a part is eliminated as a possible metric to assess its difficulty.

A second characteristic of solid models which must be considered is the number of features used to make the model. As shown in Figure 2, two identical parts can be made using different number of features. Typically, the number of features used to make a part is user-dependent and therefore, is not a consistent and reliable method to quantify a part's difficulty. Another method to measure difficulty of a solid model is to conduct a survey of CAD modelling experts. In this method, a set of three-dimensional solid models are presented to survey participants, and they are asked to rate the difficulty of the solid models on a Likert scale[13]. This method implicitly and inherently captures all aspects of a solid model's difficulty, and the method is quantitative allowing for machine learning to be performed on the results.

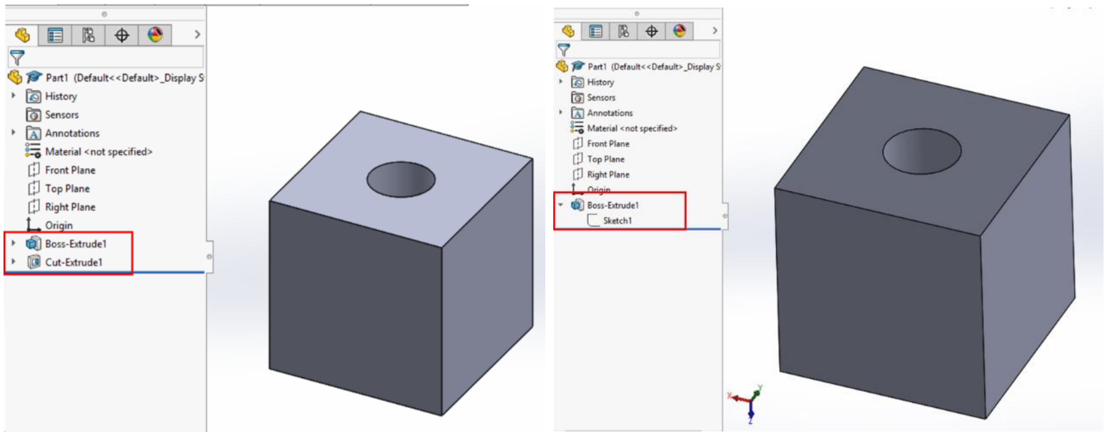


Figure 2: Example of the same solid model constructed using different features

Developing a Model to Define Assignment Difficulty

The objective is to relate characteristics of a solid model to its difficulty. To do this, the steps enumerated in **Figure** 3 are followed.

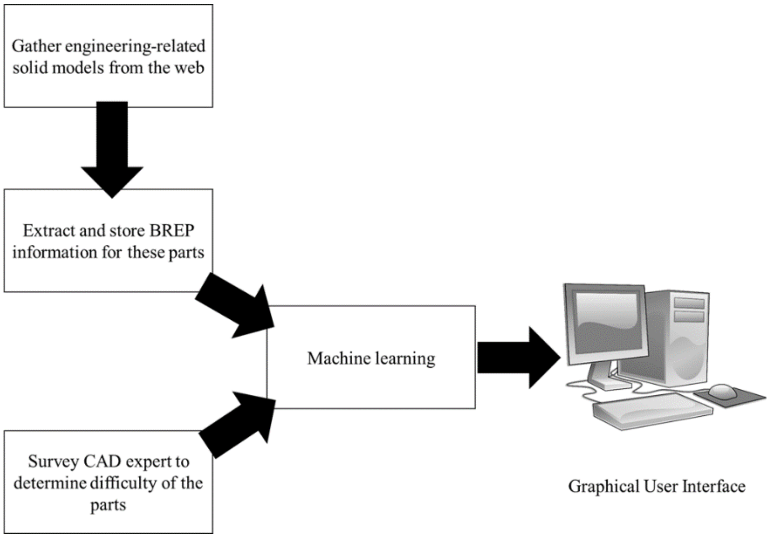


Figure 3: Steps for Developing a Model to Define Assignment Difficulty

1. *Gather engineering-related solid models from the web*
   To do this, a Python script was written to scrape SolidWorks© files from McMaster Carr [https://www.mcmaster.com/]. A total of unique 272 files were obtained by this method. These files are available at http://people.fmarion.edu/rrenu/ASEE-SE2019EG/.

2. *Extract and store BREP information for these parts*
   A Visual Basic script was written and used to extract Boundary Representation (BREP) information[14] from each of the 272 files. BREP information is extracted and later used to characterize solid model difficulty. BREP is a commonly used standard to describe/construct 3D solid models. Using BREP information ensures that the methodology employed in this research is not limited to SolidWorks files alone.

   For each model, the following were extracted and stored:

   - Total number of vertices
   - Total number of edges
   - Total number of loops
   - Total number of faces

3. *Survey CAD expert to determine difficulty of the parts*
   An expert in solid modeling and CAD was surveyed and asked to rate each of the 272 models on a 1 (Very Easy) to 4 (Very Difficult) Likert scale[13]. The expert has over ten years of experience with 3D CAD modelling, and has taught Engineering Graphics for four years.

4. *Perform machine learning to develop a model that relates BREP information and difficulty scores*
   The ratings from the expert and the extracted BREP features were fed to a J48 Decision Tree analyzer from WEKA[15]. This is a C4.5 algorithm for building decision trees[16]. It was found that this decision tree was largely insensitive to the number of folds used, and therefore the default ten folds were used.

The decision tree obtained is presented in Table 1 and the confusion matrix is presented in Table 2. The confusion matrix shows actual classifications on the rows and predicted classifications on the columns. This matrix allows for an understanding of true and false positives, and true and false negatives. For example, the second column of the first row shows that there are four instances of "Very Easy" models that have been classified as "Easy".

Table 1: Decision Tree Analysis Results

```
Edges <= 32: Very Easy (84.0/25.0)
Edges > 32
|  Loops <= 30
|  |  Loops <= 24
|  |  |  Faces <= 20
|  |  |  |  Loops <= 17: Very Difficult (2.0)
|  |  |  |  Loops > 17: Easy (11.0/1.0)
|  |  |  Faces > 20: Very Difficult (3.0)
|  |  Loops > 24: Easy (41.0/1.0)
|  Loops > 30
|  |  Vertices <= 184
|  |  |  Loops <= 47
|  |  |  |  Edges <= 162: Easy (24.0/7.0)
|  |  |  |  Edges > 162
|  |  |  |  |  Edges <= 174: Very Difficult (6.0/1.0)
|  |  |  |  |  Edges > 174: Easy (2.0/1.0)
|  |  |  Loops > 47: Difficult (18.0/5.0)
|  |  Vertices > 184: Easy (72.0/18.0)
```

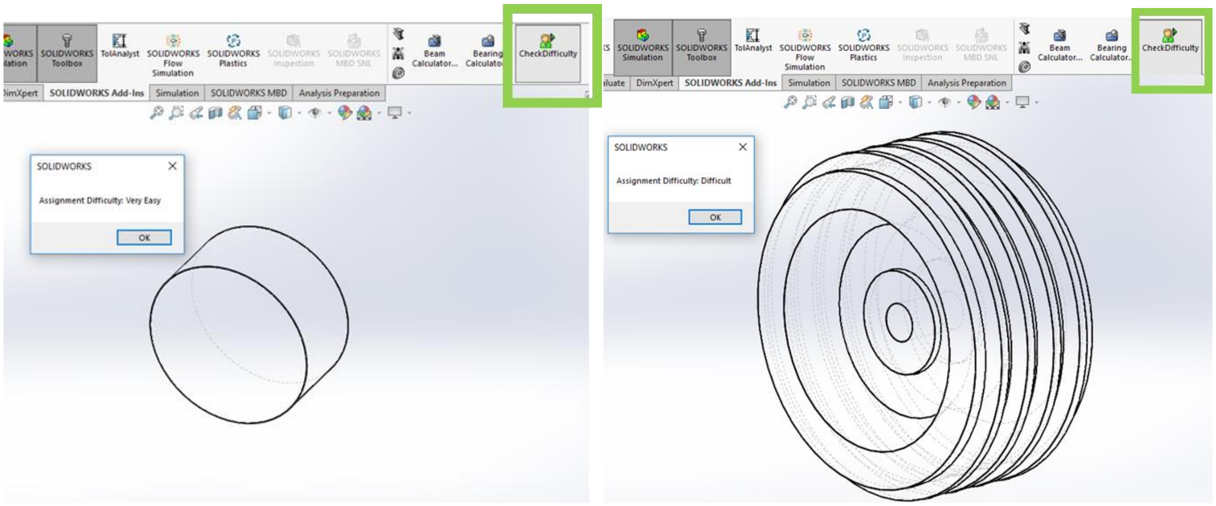
Table 2: Confusion Matrix

	Very Easy	**Easy**	**Difficult**	**Very Difficult**
Very Easy	57	4	0	0
Easy	12	117	5	3
Difficult	9	15	9	3
Very Difficult	4	18	2	5

As it can be seen, the decision tree analysis does not yield accurate results, and the decision tree will lead to several false positives and false negatives. Shortcomings and opportunities for improvements are discussed in the last section.

User Interface to Rate Solid Model Difficulty

The rules from the decision tree are implemented as a macro in SolidWorks (see Table 1). This macro allows instructors and students of engineering graphics to assess the difficulty of a selected solid model.



SOLIDWORKS

Assignment Difficulty: Very Easy

SOLIDWORKS

Assignment Difficulty: Difficult

Figure 4: Graphical User Interface to Check Assignment Difficulty

Conclusions and Future Work

This paper presents a method to rate difficulty of solid models for use in engineering graphics education. A GUI to rate the difficulty of a given solid model is also presented. This GUI can be used by instructors and/or students to assess model difficulty. The method employs results from a survey, BREP information from solid models, and a supervised machine learning process to rate difficulty of solid models. This research is limited by the fact that only one survey participant’s data was used, and BREP information was represented as only summations. However, the method established shows potential and can be improved upon by performing the following tasks:

1. Use multiple raters to gather survey data about solid model difficulty.
2. Perform thorough statistical analyses (inter-rater agreement, hypothesis testing) to assess validity of survey results.
3. Explore the use of hierarchical BREP data (faces have loops, loops have edges, edges have vertices) instead of simply using summed values for loops, faces, edges, and vertices for an entire model.

After performing the research listed above, a repository of solid models, their 2D drawings, and the associated difficulty ratings can be made available to instructors and students of engineering graphics. Additionally, the rules governing the GUI (shown in Figure 4) must also be updated.

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Dr. Rahul S. Renu

Dr. Renu is an Assistant Professor in the Department of Physics and Engineering at Francis Marion University. He holds three degrees in Mechanical Engineering, and the focus of his doctoral research was knowledge management in design and manufacturing. He teaches courses related to materials, manufacturing, engineering graphics, and engineering design.

Dr. Brett Shields

Brett is a faculty of Industrial Engineering at Francis Marion University. Brett holds a PhD in Industrial Engineering from the University of Tennessee, a MS in Mathematics from East Tennessee State University, and a BS Mathematics from King University. Brett's research interests are in mathematical optimization and engineering education.