Title:
**Training Engineers in the Use of Constraints to Create Quality 2D Profiles for 3D Models**

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Introduction:
The development of computer-aided three-dimensional design applications (CAD 3D) has transformed the product development process and has introduced a new paradigm of Model-Based Enterprise (MBE). This principle draws on the use of annotated CAD models as primary elements to support the design, analysis, and manufacture of industrial products. These annotated CAD models contain data and additional information necessary for production and support. For this reason, CAD model quality is essential, since the quality of manufactured products depends on the quality of their data [10]. Consequently, poor data quality compromises CAD model reuse, which is a primary benefit of history-based parametric modelling software. A model is reusable if it allows modifications in other situations while maintaining its design intent [7]. Previous studies revealed that nearly 50% of CAD models fail after making alterations [9]. Reusability and the interoperability of a model are the most common functions in MBE. To this end, the model must also be robust and flexible [2-3]. Constraints are commonly used to acquire robust and flexible profiles that allow for redesign while preventing undesirable geometric changes. Robust profiles must be completely or fully constrained [4]. Profile flexibility does not depend on the quantity of constraints, but on their semantic level, and the proper selection and introduction of geometric constraints in 2D profiles determines their applicability for reuse.
Various authors have proposed different classifications constraints [11], [1], [6]. We classify constraints as:

- Dimensional.
  Constraints that define the size and dimensions of the profile.
- Geometric.
  Constraints that define the geometric relationships between the elements of the profile.
- Position and orientation.
  Constraints that relate the profile to the coordinate system.

We strongly believe that over-constrained profiles with redundant relationships are more difficult to edit than those that avoid redundancies. Many experienced CAD instructors have observed that engineers often use redundant relations when creating 2D profiles and that this practice prevents the creation of reusable CAD models. Our goal is to train novice CAD users to create quality parametric 2D profiles based on robust and flexible 3D models for future reuse. In preceding work [8], we conducted an experiment examining if engineers were able to: (1) identify fully-constrained profiles and (2) detect the types of constraints that were used. Results indicated that more than half of trainees failed to identify which profiles were properly constrained and they also could not identify the type of constraints used in a given example. We concluded that improvements were necessary in training engineers in these skills. In this paper, we present a strategy to reinforce student training through simple exercises paired with quick and effective feedback. This approach facilitates student performance in identifying and avoiding redundant 2D constraints when creating 2D profiles.

Main idea:

In a previous study by González-Lluch and Plumed [8], a pilot experiment was performed with students enrolled in a "Graphics Engineering" course (third sequential class in an undergraduate Mechanical Engineering curriculum). The results indicated that novice CAD users failed to identify constraints in sample CAD files even when the examples were at low levels of difficulty. Students were trained to create robust and flexible 2D profiles following the first chapter of an instructor-authored text [5]. This book is aimed for basic 3D CAD courses in mechanical engineering and product design grades and in the first chapter, three-dimensional geometric modeling and parametric design of profiles are covered. Moreover, they also received instruction on constraints in additional theoretical and practical-based classes (using SolidWorks®).

In a continuation of this research focus, a new strategy has been introduced to students in a class entitled, "Computer-aided Design II," which is the third sequential course in an undergraduate Industrial Design and Product Development Engineering curriculum.

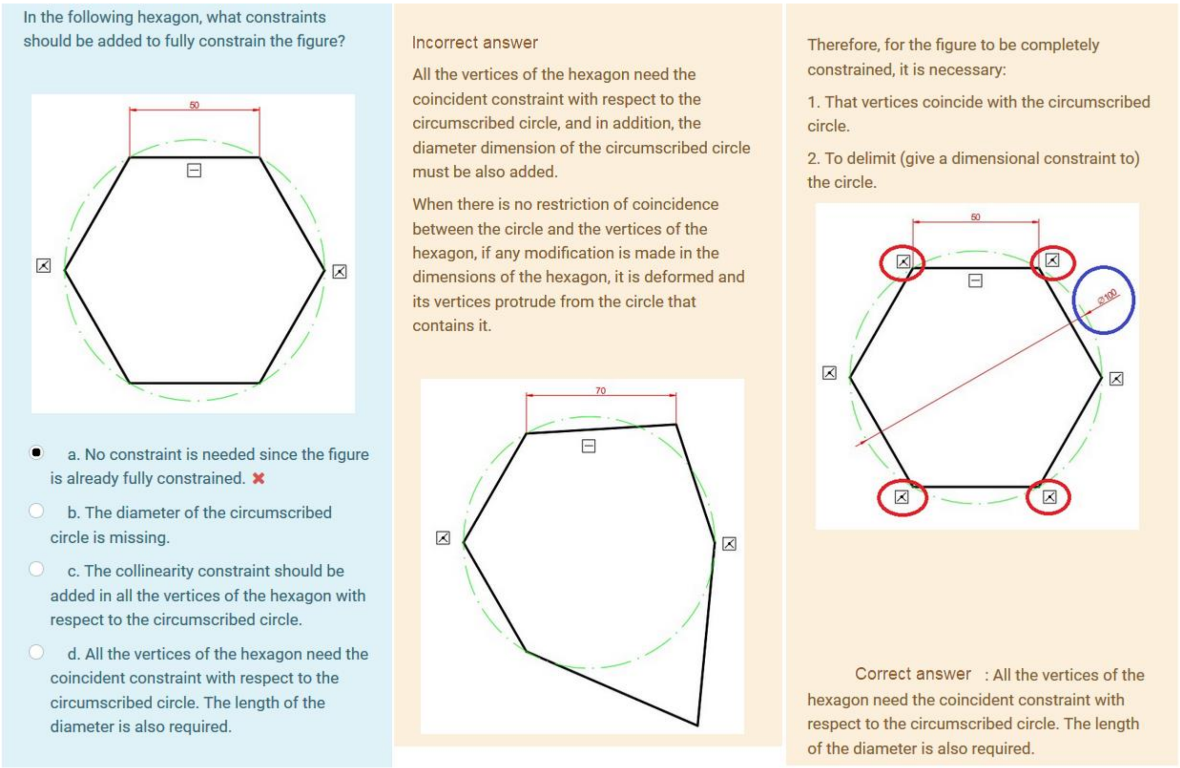


Fig. 1: Example of a question with incorrect answer and the feedback obtained.

A supplemental activity was designed to improve novice skills with respect to understanding 2D constraints and consists of an eight-question survey, with corresponding figures. The online questionnaire was delivered through a virtual classroom environment as an optional assignment. Each isolated question is displayed full screen, to capture a student's undivided attention, in multiple-choice format. Questions were delivered in random order. If a student supplies an incorrect answer, the questionnaire provides comments with explanations of the correct answer, as shown in Figure 1. The online platform collects a register of student responses. Students were unable to alter their answers once they were submitted and there was no time limit to respond.

The effectiveness of the training activity was assessed during the midterm exam. The students were required to solve two questions related to constraints, using the same questions that were proposed by González-Lluch and Plumed [8]. The first question queried students about whether the profile shown in Fig. 2(a) was fully-constrained, over-constrained, or under-constrained. The correct response is that this 2D profile is fully-constrained, and this answer is easily verified when using a 3D CAD application (ex. Solidworks®), as shown in Fig. 2(b).

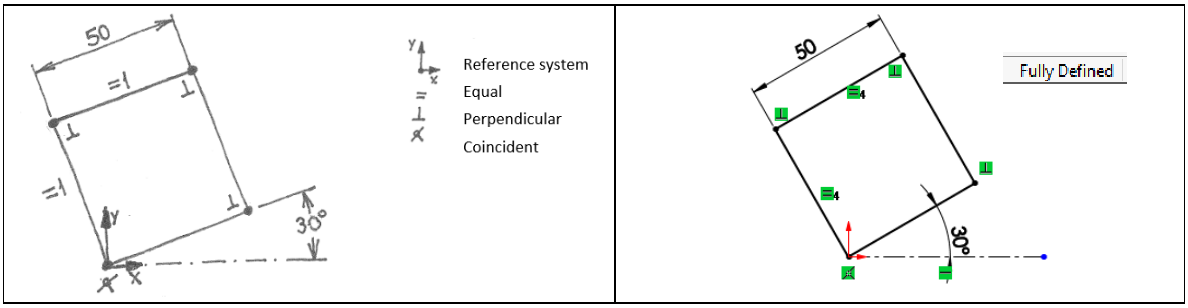


Fig. 2: (a) The first question of midterm exam (left), and (b) verifying the same sketch using Solidworks® (right).

The second question referred to the same sketch used previously. Students were required to identify and locate each type of constraint (listed below):

- Dimensional or geometric (F)
- Position and orientation (P)
- Others (B).

The students also were required to explain their answer. Bearing in mind the possibility of multiple correct answers, we consider that the 2D profile includes the following constraints (Fig. 3):

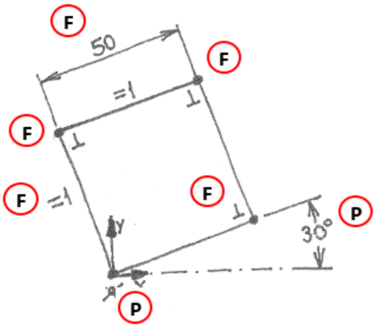


Fig. 3: Correct answer for second question.

Results reveal that more than half of the students correctly answered the first question. In fact, the percentage of correct answers was slightly higher in the trained group (67.5%), than in the group of students that did not perform the reinforcement activity (61.1%).

Regarding the second question, results reflect that although the percentage of correct answers of the trained group (37.5%) is slightly higher than the No-trained group (33.3%), students generally are deficient in their ability in classifying the types of constraints.

Conclusions:

Our primary idea is that the effective use of constraints during the creation of 2D profiles to build 3D models improves CAD model quality since constraints help to convey design intent and permit subsequent reusability of 3D CAD models. According to previous studies, many designers, engineers, and students oftentimes apply redundant constraints during the creation of parametric profiles when using 3D MCAD applications.

We conclude that although students understand geometric constraints, they focus solely on dimensional constraints when determining if sketches are completely constrained. Therefore, continuous and autonomous learning is needed to reinforce these skills. Furthermore, results of the questionnaire on the perception of the activity reflected positive opinions about its utility. The next step in this process consists of building exercises designed to create awareness in trainees about the importance of reusability in 3D MCAD models. As a future development, we suggest another useful strategy, which is to design an online checker which would act as a filter of quality errors at the semantic level in the 2D parametric profile. In this way, students would possess the tools necessary to train themselves by performing the exercises and receiving automatic feedback. This strategy is expected to provide the advantages of reducing the teaching workload while developing independent learning capacity in the students.

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