Title:
Impact and Effect of Formative Feedback Improvement for Dormant Deficiencies in MCAD Education

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Keywords:
Computer-Based Feedback Provision, Student Self-Assessment, Skill and Competency Development, Dormant Deficiency, Design Intent, CAD Model Quality and Robustness

DOI: 10.14733/cadconfP.2025.93-97

Introduction:
In mechanical engineering CAD (MCAD) education, it is still a challenge to provide timely, high-quality, personalized feedback (cf. [6,8,12]) in order to help students with learning and skill development aimed at creating well-designed and robust parametric CAD models, which are central for product and part family development. Tools and methods using automated grading as described, for example, in [1,2,3,5,7] are limited by their metrics and by their assessment approach. In particular, the metrics they use are of a rather static and exclusive nature, relying heavily on the final outcome. That is to say that they rely upon the completed CAD model, which then has its data structure compared with that of a fixed reference solution. Such approaches are not structured suitably to assess CAD model quality in regard to robustness and alterability, due to their static and exclusive nature, which usually leads them to discount CAD model regeneration processes and their impact after alteration. They are also not sufficiently structured to explicitly support formative self-assessment carried out by students during individual steps of the modeling process as part of their exercise work. This problem arises because the software tools used are unable to assess partially created CAD models, since they appear to be incomplete according to the metrics and rubrics provided in relation to the exercise specification and the fixed reference solution associated with it.

As part of continuing improvements to an MCAD course that was restructured by the authors lately, several of these issues have been addressed. In particular, the issue of feedback provision was approached by introducing the dormant deficiency concept and metric. This concept includes three types of dormant deficiency (cf. [9,10]) and is aimed at supporting students in acquiring the knowledge and skills development needed to create robust alterable CAD models. This novel concept, and the associated classification system, come with a metric which facilitates description and quantification of the impact that errors in feature associativity can have on parametric feature-based CAD models (cf. [8,9,10]). Those errors in associativity, which were introduced during the modeling process due to mistakes in the specification of dependencies between geometric entities, remain dormant until an actual CAD model regeneration is triggered and executed through an alteration.

To provide a means for students to see this concept coming alive, as well as having timely high-quality feedback on this metric applied to the CAD models which they have created in the CAD laboratory and in exercise assignments, a software-based feedback agent (cf. [8]) has been developed. Within one of several spin-off projects, this software-based feedback agent, that was developed and provided to all MCAD students, was extended and improved substantially (cf. [9]). The results and outcomes of that project are reported in this paper.

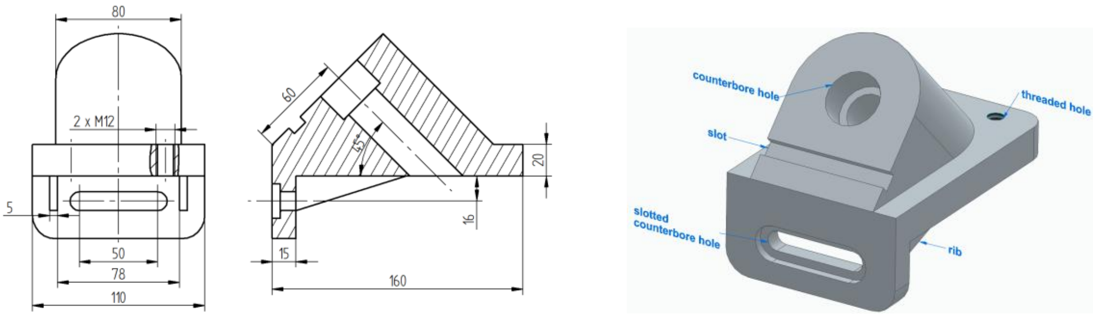
Research Questions, Data Sets, and Method:

The objective of the second step of this project follow-up study was to determine and verify qualitatively and quantitatively the impact of the improved educational intervention. Outcomes of that were then used to identify areas for improvement in a manner allowing for adjustment and refinement so as to ensure that, in the long run, this educational intervention will be able to sustain its quality and provide substantial benefits while still retaining effectiveness and efficiency. In particular, the study presented in this paper addressed the following research questions:

RQ1: What was the efficacy and progress of the educational intervention in the form of extended and improved software tool-based formative feedback in the context of creating robust parametric feature-based CAD models?

RQ2: Which areas and directions for improvement can be identified for adjustment and refinement to ensure that, in the long run, this educational intervention will be able to sustain its quality and provide substantial benefits?

The study was conducted through a quasi-experimental research design with two sets (control / experimental) of student-created CAD models. The control set consisted of CAD models that had been submitted by students who did not make use of the improved software-based feedback agent. The experimental set consisted of CAD models submitted by students who used the improved software-based feedback agent. Students of both groups were in their second year of undergraduate studies. All CAD models used in the study were created as part of concrete exercise assignments and CAD laboratory activities (see Fig. 1), which are components of an actual CAD course for mechanical engineering at the institution where the authors operate. The system implementation and feedback agent deploy a commercially available parametric feature-based solid modeling system, namely *SolidEdge* from Siemens Digital Industries Software.



(a) (b)

Fig. 1: Example of an actual CAD Course exercise assignment. From left to right: (a) outline and overall dimensions of the CAD model, (b) rendered shape of the CAD model.

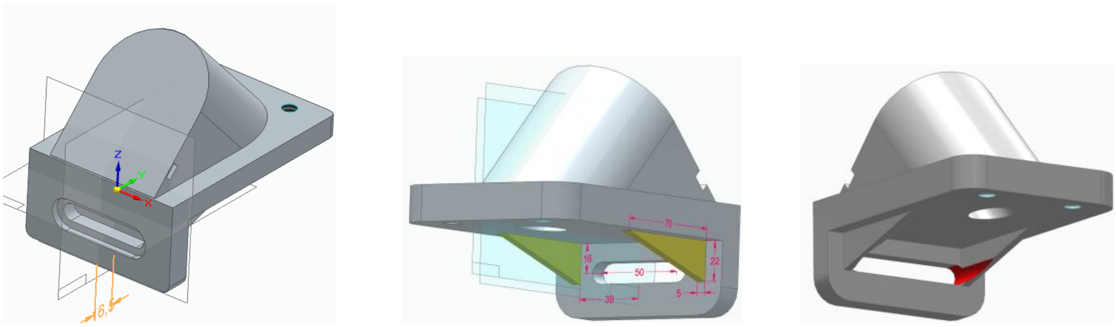
After initial model validity and data integrity checks, a total of $N = 80$ (control $n = 19$ / experimental $n = 61$) student-created CAD models were deployed in the observational study. All CAD models that were deployed in the study were analyzed and assessed individually by the authors. Results obtained were then cross-checked to verify the accuracy, correctness, and integrity of the analysis and its outcome.

Analysis, Results, and Discussion:

Considerable improvement in student performance and in learning outcomes could be achieved through the extension and improvement of the agent-based formative feedback. Analysis and assessment of the feature-based CAD models created by students using the improved agent-based formative feedback throughout a series of design and modeling exercises showed that the proportion of CAD models that contained dormant deficiencies decreased significantly compared with the proportion of models by students who did not use it. For the CAD model set discussed in this paper (see again Fig. 1), this proportion was reduced from 57.89% to 27.87%. The calculated individual odds yielded an odds ratio OR = 3.559, which, using the common conversion method described in [11], translates into a standard effect size measure (cf. [4]) expressed as Cohen's d = 0.701. The odds ratio has an approximate 95% confidence interval CI = [1.222, 10.365] with the approximate standard error of the log odds ratio $SE(\ln(OR))$ = 0.5453.

These results show that the overall odds that a CAD model would contain a dormant deficiency were a little above 3.5 times as high for a CAD model that had been created by a student without the improved feedback intervention as for a CAD model that had been created by a student with the improved feedback intervention. As the confidence interval does not include an odds ratio of 1, the result is statistically significant at the 5% level. This outcome is further confirmed through the chi-square test (df = 1, χ^2 = 5.7412, p = 1.657e-2), which also yields a statistically significant relationship at the 5% level between the presence or absence of dormant deficiencies and CAD models that were created without using any feedback intervention and those that were created with improved feedback intervention.

Detailed analysis of the student-created CAD models that contained dormant deficiencies revealed the nature and structure of several issues related to those deficiencies. For example, in cases of CAD models with type I dormant deficiency, the most common issues were related to the use of constraints. Using either more or fewer constraints than necessary resulted in over- or under-constraining, either of which is prone to produce inconsistencies when CAD models are altered and regenerated, as is the use of inadequate or incorrect constraints. A typical example of the last-mentioned, encountered during analysis, is shown in Fig. 2(a). Here, the inclined plane of the semi-circular flange is constrained incorrectly in regard to the upper frontal edge of the L-shaped base (see again Fig. 2(a)). Hence, after CAD model alteration, the features that should be located on this plane lose their reference to it, and consequently are not regenerated correctly.



(a) (b) (c)

Fig. 2: Examples of CAD models displaying the effect and impact of dormant deficiencies after parameter changes and model regeneration. From left to right: (a) regenerated CAD model with type I dormant deficiency where some of its features affected by alterations are not regenerated correctly, (b) CAD model with type II dormant deficiency before regeneration, (c) regenerated CAD model with type II dormant deficiency containing visible deficiencies in features affected by alterations.

In cases of CAD models with type II dormant deficiency, the most common issues were related to a lack of understanding of how to use the command for creating slot features correctly and the use of constraints. However, the latter was of a nature different from the cases of CAD models with type I dormant deficiency. Here, over- or under-constraining was not an issue, but using constraints correctly, mostly within profile definitions, to properly define relationships between geometric entities at the inter- or intra-feature level was a problem. A typical example of the former, encountered during analysis, is shown in Fig. 2(b). Here, the slot feature was positioned in a manner so as to remain symmetric in respect to a referenced plane, as shown in Fig. 2(b). The first rib feature was created by defining its profile on a plane that was parallel to the plane referenced, while being positioned at a finite distance from it. Taking advantage of these symmetric conditions, the second rib was created using a mirror copy feature. However, if the inter-feature relationship between the length of the slot feature and the position of the first-created rib feature is not correctly defined, critical situations lead to the introduction of dormant deficiencies. The resulting effect and impact are shown in Fig. 2(c).

In reference to research question RQ1 concerning the outcome and performance of students in relation to the quality and robustness of the CAD models that were created after the introduction of extended and improved software tool-based formative feedback, a significant improvement was observed. This was reflected in, among other factors, a significant decrease in dormant deficiencies and a considerable increase in the effect size of this educational intervention. Based on observations made during the CAD course, this level of learning outcome and skill development appeared to have been achieved faster by students who used the improved feedback. This suggests that the improved feedback intervention engages students in more effective actions that help improve existing behavior, knowledge, and skills, which is the basic goal of any learning experience.

Regarding research question RQ2, results from the detailed analysis, some of which have been outlined earlier, indicate that defining constraints properly – especially the definition of profiles and geometric properties – to avoid type II dormant deficiencies is still problematic for students. On the other hand, many of the critical situations identified could have been avoided by reducing the sometimes-unnecessary complexity of constraints as used by students. In many cases, this can be achieved by using formulae. For example, in the case shown in Fig. 2(b) and Fig. 2(c), a variable that defines the proper rib location within the CAD model can be defined in a straightforward, non-complex manner by using a formula taking into account the length and width of the slot and the offset of the ribs from it. This discovery has led the authors to consider modifications to the CAD course by adjusting parts of the lectures and CAD laboratory exercises to increase the focus on both the creation of proper constraints that are less complex and the use of formulae.

Conclusions:

The results obtained from the second step of this project follow-up provide tangible evidence that the extension and improvement of agent-based formative feedback has indeed led to improvements in student performance. This was reflected in a considerable reduction in dormant deficiencies in student-created CAD models and a significantly increased effect size of this feedback intervention, among other factors. Here, advancing learning experiences and skill development not only enabled students to create CAD models that were more robust and of better quality, but also reduced the learning time while accelerating progress in student performance. This is due in part to this educational intervention explicitly supporting self-assessment and the self-adjustment efforts of students. These results also indicate not only that this educational intervention is able to sustain its quality and provide substantial benefits while still retaining effectiveness and efficiency, but also that it provides a supporting foundation for exploring innovative means aimed at improving modern MCAD education, such as novel key metrics for indicating success in achieving a desired learning outcome.

Guided by the results obtained through the second step of this project follow-up, as outlined in this paper, and by the insight gained for advancing both the CAD course outcome and the student learning experience, the following measures are currently being designed with the aim of implementation for the next academic year. First, the MCAD course will be adjusted by fine tuning some parts of the lectures and some CAD laboratory exercises and course assignments. This will include the more prominent use of formulae and a deeper focus on the role of correctly and fully constrained profiles. Second, rather more lecture time will be dedicated to the relationships which exist among best practices, the creation and use of well-structured profiles, and dormant deficiencies, especially in regard to their impact on the quality and robustness of CAD models. Third, adjustments will be made to some of the questions on the survey that is conducted by the authors every academic year in parallel with the MCAD course. This survey aims at eliciting feedback from students on how they perceive the adjustments which have been made to the course, and whether the adjustments have improved the learning experience.

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