Title:
Formative Feedback Improvement in MCAD Education: Supporting Knowledge-Driven Dormant Deficiency Detection and Analysis

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Introduction:
Many experts consider formative feedback to be a crucial element of appraisal and evaluation in the learning process. Its potential for improving performance and enhancing learning outcomes is widely acknowledged in most fields and disciplines. However, as studies on the effectiveness and usefulness of feedback interventions have demonstrated, educational intervention is complex and does not always guarantee the pedagogical success expected (cf. [6,14]). With the increasing popularity of online course provision and e-learning environments in higher education, the implementation and provision of feedback based on software tools and digital systems is rapidly gaining traction. With those computer-based approaches, personalized and immediate feedback can be provided at levels that are not feasible through human-based agents in traditional educational settings. This is especially the case for introductory CAD courses, where the number of students tends to be quite high as those courses increasingly move into the curriculum of basic undergraduate education in various disciplines. Although structuring and providing feedback appropriately in a computer-based environment poses considerable challenges, there is also great potential to address most of the issues relating to how to achieve effective and useful feedback. If the matter is approached adequately, the students should first have a choice whether or not to receive feedback. If they choose to receive feedback, it can be provided immediately and on-demand through interactive communication between human users and computers, allowing it to be timely and multiple-try in nature. The feedback can also be tailored to individual needs and is thus highly personalized and task/process specific.

Most software tools supporting the automated grading and assessment of CAD models, such as those currently provided to students in CAD courses at institutions of higher education, are limited by their metrics and by their assessment approach (cf. [1-5,7-9]). 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 to 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-assessments 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. To address those shortcomings outlined above, among other issues, a software-based feedback agent has been developed, and this was introduced during the

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restructuring of a mechanical engineering CAD (MCAD) course. To translate the insight from lessons learned into improvements of and support for this feedback intervention recently introduced within the MCAD course, a two-step project follow-up was initiated, with results from the first step being reported in this paper.

Background, Scope, and Objectives:
The project follow-up described in this paper is a spin-off project that expands upon previous work. That is, representing continued improvements of a MCAD course that was restructured lately. A selection of some major project milestones, with related results and outcomes achieved, is shown in Fig. 1, together with those of the recently initiated project follow-up.

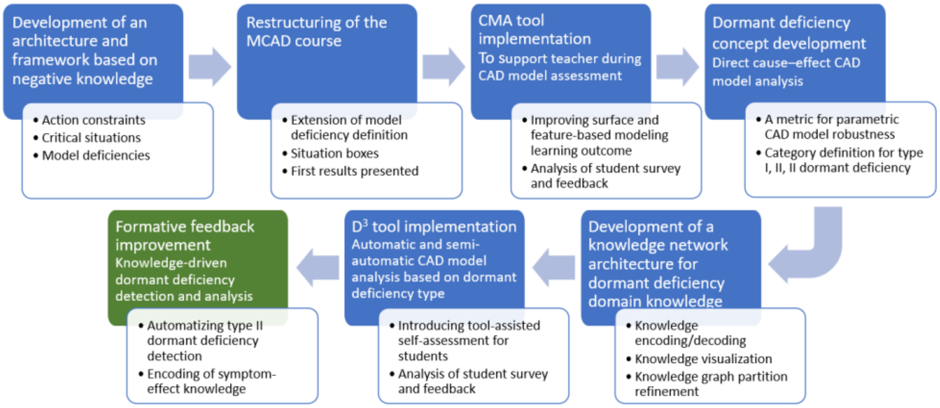

Fig. 1: Overview of development stages of the restructuring of an MCAD course depicted through a selection of project milestones with related results and outcomes.

The restructuring of the MCAD course consisted of various types of improvement, including the development of negative CAD domain knowledge and expertise, as well as the development of the working knowledge and skills required to create robust, alterable parametric CAD models. The latter was approached by introducing the dormant deficiency concept and metric. This concept includes 3 types of dormant deficiency (cf. [12]) and is aimed at supporting students in acquiring the knowledge and skill development needed to create robust alterable CAD models. 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 that they have created in the CAD laboratory and in exercise assignments, a software-based feedback agent was developed, and subsequently provided to all MCAD course students. Analysis and evaluation of project outcomes, a survey, and engagement with students during lectures and exercises provided several precursors for improvements required and for the directions in which those might be pursued. One such indication was the need for improvement of the feedback – generated by the software-based feedback agent – related to type II dormant deficiencies.

Type II dormant deficiencies are part of a novel dormant deficiency concept and classification system, with a metric that allows for describing and quantifying the impact that errors in feature associativity can have on parametric feature-based CAD models (cf. [12]). 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. As type II dormant deficiencies relate to faults in shape, the effect of this type of deficiency is that a regenerated CAD model does not contain any features labeled with a warning or failed status, but the shapes of features are incoherent or even destroyed completely. An example of this is where a cutout feature is partially moved outside the geometric boundary of the target body. The main symptom of a type II dormant deficiency that has been activated is a change in the local topology of the features affected by this deficiency.

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The objective of the first part of this two-step project follow-up was to improve both the amount and the quality of the feedback information provided by the software-based agent in relation to type II dormant deficiencies. This, in turn, required the formalization and encoding of domain knowledge on type II dormant deficiency symptoms and effects, and their relationships, upon which autonomous computation of information related to this type of deficiency can be based, in order to improve the provision of agent-based feedback.

Approach and Development:
Considerable improvement in student performance and in learning outcomes was achieved with the previously introduced feedback-based educational intervention (cf. [10,11]). However, it also became evident that students still have difficulties when it comes to handling and correcting shortcomings and errors in their CAD models in regard to type II dormant deficiencies. This led to a focus, within this project follow-up, on extending and improving the quality, scope, and detail of the feedback – generated by a software-based feedback agent – by offering more information on type II dormant deficiencies. This includes, among other feedback components, information on which features are affected/involved, the effect the type II dormant deficiencies have on those features, and where those features are located in the CAD model. Also provided to students are the type of change, the range, and the point values of feature parameters, such as hole or pocket dimensions, which are related to the symptoms and the effects the type II dormant deficiencies produce on those features affected.

The extended feedback is provided through list-based information and visual representation of type II dormant deficiency-related symptoms and effects, supported by selective feature shape coloring and transparent CAD model shape rendering, and brushing (see Fig. 2). This (cf. [13]) allows users to directly visualize and access affected features and their parameters in the CAD model through interactive means such as pointing to and clicking on entities within list-based information from the feedback provided. Further details and requirements for the design of the formative feedback extension were driven by factors related to technological issues pertaining to the data structure access of the commercially available CAD system used, the functional scope in regard to fully automated dormant deficiency detection, and, most importantly, the needs of the MCAD course students. This was determined to a large extent through the results of a formative usability study of the software-tool-based feedback agent, a student survey, and observations made through interactions with students during the MCAD course lectures and the CAD laboratory exercises (see also reports in [10,11]).

Development and implementation of feedback improvements in regard to type II dormant deficiencies, as outlined above, were carried out within several prominent project steps, as follows.

First, a systematic analysis of computed type II dormant deficiencies was conducted, which endeavor was supported by extensive empirical studies to gain a deeper insight into type II dormant deficiency symptoms. This was achieved by taking into account the nature of the dormant deficiency (cf. [12]) and carrying out structured analyses that focus on a change in the local topology of individual features affected by the type II dormant deficiency. The results were then used to compile symptom categories for type II dormant deficiencies in regard to individual feature types.

Second, a further round of empirical studies was conducted to aid a detailed analysis of the effects that type II dormant deficiencies have on individual features. This analysis of effects was based on symptom categories, which were created in the previous step outlined above. The results of this second round of empirical studies were used to compile effect categories for type II dormant deficiencies in regard to individual feature types.

Third, the results from the previous two studies, in the form of symptom categories and effect categories for type II dormant deficiencies, were used to compile and formalize knowledge on symptom and effect relationships for this dormant deficiency type in regard to individual feature types.

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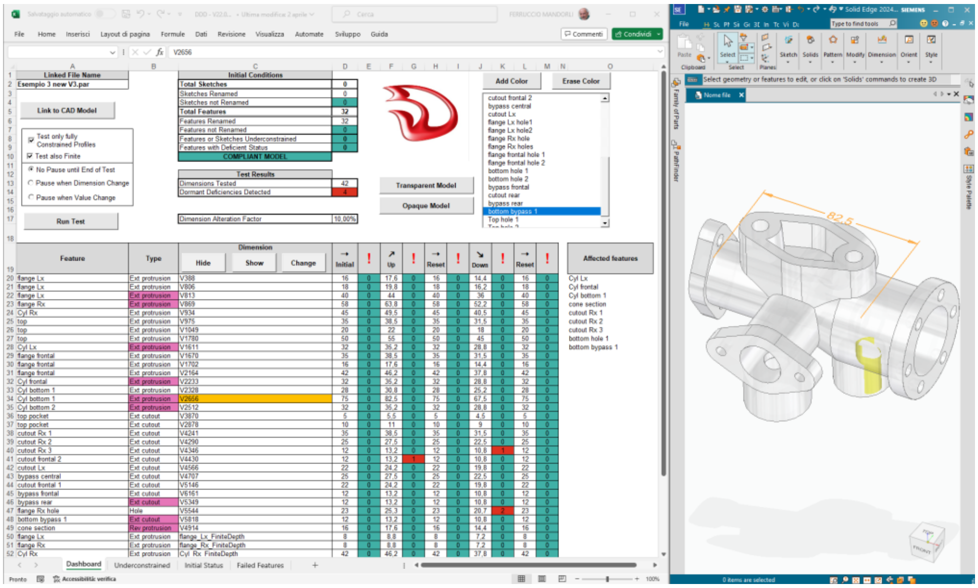

Fig. 2: Example of the visual simulation display showing elements of the extended feedback and new functionality, as well as user controls that were added to the software-based feedback agent.

Next, the formalized knowledge on symptom and effect relationships for type II dormant deficiencies, in regard to individual feature types, was encoded using a knowledge network that is based on attributed *r*-partite graphs (cf. [12]). In particular, graph partitions related to symptom categories and effect categories for type II dormant deficiencies were extended through newly created partition refinements.

Finally, the results of the previous steps, as outlined, were implemented as extensions of the software-based feedback agent. This feedback agent, in turn, is an integrated part of a larger computerized tool system for MCAD education that includes, among other components, a parametric CAD model alteration simulator and a visual simulation display (cf. [10]). Further extensions include added functionality that permits student users to enable and directly control – through the graphical user interface of the tool system – transparent CAD model shape rendering and selective feature shape coloring. This fully supports knowledge-driven detection and analysis of type II dormant deficiencies in regard to their symptom and effect relationships, and it is upon this foundation that extended formative feedback enriched in quality through visualization and offering more detailed information on those dormant deficiencies can be autonomously generated by the software-based feedback agent.

Summary and Outlook:

Within the work presented, the approach, structures, and framework used for the formulation and encoding of domain knowledge on type II dormant deficiencies and their symptom and effect relationships have been outlined and discussed. This encoded domain knowledge has been integrated into a knowledge network that is linked to a software tool-based formative feedback agent, which was provided to students in a recently reformed MCAD course. This extension of the agent-based formative feedback was driven by tangible evidence of previous project outcomes and is aimed at improving learning experiences and skill development during CAD laboratory exercises and course assignments, particularly supporting the self-assessment and self-adjustment efforts of students while practicing the design and creation of robust, alterable parametric feature-based CAD models.

The second step of this project follow-up is planned for this academic year and the next. It includes releasing the improved and extended software tool-based formative feedback agent and

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monitoring the efficacy and progress of this educational intervention. The latter will be based on student performance assessment and online student surveys – among other criteria – to discover whether the feedback improvements, as implemented, actually translate into measurable results as anticipated. Depending on the outcome, further project follow-ups and spin-off projects will be considered in regard to student engagement, continuous improvement, and sustainability. The aim is to provide opportunities to engage with students in order to learn more about their concerns and needs. It is necessary to identify areas for improvement in a manner that allows 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.

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