Title:
Parametric Feature-Based Solid Model Deficiency Identification to Support Learning Outcomes Assessment in CAD Education

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Introduction:
In science and engineering at institutions of higher education, didactic pedagogy is still the dominant and most common method of teaching CAD. This represents a traditional, behaviorism-oriented approach with the aim of providing students with basic knowledge and skills. In particular, within CAD education the traditional approach to teaching is based on the use of tutorials and practical examples, along with definitions of guidelines and best practice. This is considered sufficient for building CAD models with specific CAD systems representing the shape of a part subject to design. Here, the content of the subject matter, as related to the modeling process, is broken down into individual behavioral steps reflecting algorithms needed to build the topology and geometry of the model and the sequences of commands to operate the CAD system accordingly. Therefore, it is supporting the deficiencies of modern CAD systems, which are heavily based on geometric modeling techniques. This is due to historical reasons related to the development of the design and the manufacturing processes that evolved around the geometric shapes of parts and products. In such a scenario of traditional CAD education, learning outcomes obviously lack the components that link different aspects of the CAD model created to actual design intent and the resulting model structure.

Recent work in educational research has been aimed at creating awareness of and addressing the most prominent shortcomings and failures of current CAD education, among other issues. Such efforts have provided new insights and recommendations, although the work is still limited and the results sometimes contradictory. However, this approach is gradually increasing the empirical body of evidence for improvement, and moving steadily in the right direction. The need for educational exercises in the CAD laboratory, providing opportunities for students to experience both creation of their own models and the alteration of models created by others, is investigated and discussed in [9]. Work on promoting good design practice by relating model attributes to design intent can be found in [10]. There is a demand for a change of focus in traditional CAD education from the declarative knowledge relating to geometric algorithms and commands required for operating a CAD system, in the literature referred to as *command knowledge*, toward knowledge and expertise which can transcend a particular CAD system. This is discussed, for example, in [1,3]. This work highlights the need for higher level thinking relating to what is commonly known as *strategic knowledge*, i.e. knowledge of the different methods of achieving a specific task (goal) and knowing how to choose among those methods. Note that in this context design intent can be considered as falling under the category of strategic knowledge (cf. [2,9]). Moreover, recent developments, stemming from both the results of cognitive science in education and changes in a progressively technology-influenced and increasingly complex global labor market, attest to the need for current efforts in restructuring curricula and integrating suitable elements of alternative teaching approaches to transform CAD education so that it is more student centered and learning as well as practice oriented. It needs to be better structured so that it efficiently and effectively matches actual student learning outcomes with skills and competencies related to, among other attributes, spatial ability and mental visualization, cognitive model composition, meta-cognitive processes including planning, predicting, and revision, and modeling strategies (see also [2]). How some of these challenges were addressed and tackled from several directions within discipline-based educational research is reported and discussed, for example, in [1,7,10].

Scope and Objectives:

To translate the potential and benefit of those encouraging approaches into educational practice, however, also requires better structured and more frequent assessment and feedback than can be achieved with traditionally employed summative assessment and feedback techniques. Here, formative assessment and formative feedback appear to offer a viable solution (see also [5,6]), and these are increasingly regarded as promising and effective components within the instructional practices currently proposed for reforming higher education in science and engineering. Unfortunately, within CAD education, dedicated techniques and tools are not yet available to support the implementation of formative assessment, and, in particular, to assist the learning goals and outcome-oriented assessment of CAD models produced by students. Moreover, those frameworks and tools that are available for CAD model analysis and evaluation, and that are deployed within commercial and industrial settings, cannot be directly used in educational settings, due to differences in assessment criteria and evaluation goal settings. These differences focus mostly on issues related to application context, quality, and interoperability of CAD systems (cf. discussions and tool reviews in [4]).

Recent efforts to reform an actual CAD course, which is currently a part of the curriculum for the Laurea degree in mechanical engineering at the institution represented by the authors, addressed, among other matters, the development of modeling competencies with particular reference to the strategic knowledge required to create usable CAD models. In particular, this major course-specific learning goal, i.e., development of the strategic knowledge and modeling skills indispensable for producing usable CAD models, requires better teaching techniques that reach beyond the usual lecture-based presentation of domain-specific factual knowledge with students mostly in the role of passive learners. Moreover, it especially requires assessment techniques and feedback which are capable of adequately and frequently measuring the gap between actual student learning outcomes as achieved and learning goals as pre-assigned, while also providing high quality and timely feedback for both teacher and students. Within this setting, and in the context of higher education, as outlined earlier, the assessment of student performance and results produced in CAD laboratory exercises and course assignments needs to be conducted in a computer-aided manner. This will support implementation, while also improving the scope and overall quality of formative assessment and feedback, but it requires new approaches and tools for feature-based solid model assessment. The aim of the current paper is, firstly, to present a novel approach to feature-based solid model assessment in the educational context, which is based on deficiency analysis in relation to learning goals and outcomes; and secondly, to report on the technical architecture and concrete implementation of a newly developed software tool to enable and put into practice this novel feature-based solid model assessment approach.

Motivation, Approach and Implementation:

As pointed out above, inspection, analysis, and assessment of CAD models within an educational context are different from their (in somewhat reduced form) counterparts in commercial and industrial settings in regard to goal and assessment criteria definitions. This is most evident within formative assessment. To promote as well as advance formative feedback in CAD education, feature model and geometric model assessment needs to consider the quality of a model not only in terms of the absolute criteria that are associated with technical domain knowledge, but also by applying criteria related to model deficiencies that are the result of wrong or inappropriately applied system commands and partial or entire modeling strategies. This represents a task that is far from trivial, as assessment requires not only the detection and identification of deficiencies that in many cases do not violate general normative knowledge about feature modeling and geometric modeling (see also discussions on realism errors in [4]), but also knowledge about the modeling goals and how they have been translated into actions. Within an educational context, parts of the latter can usually be associated with learning goals and outcomes related to particular exercises and course assignments (see also overview as depicted in Fig. 1). In the context of parametric feature-based solid model assessment, analysis and evaluation need to be based on both feature-related properties/characteristics and the topology and geometry of the final modeling result. In particular, properties of individual features and characteristics of feature modeling sequences that were created for producing the final model shape can be used as a proxy for assessing particular modeling steps in a reflective and ex post facto manner. Currently, most commercially available CAD systems that support feature modeling provide interactive commands at the user interface to allow for some basic form of inquiry about model properties and the characteristics of both feature entities and topological/geometric model entities such as feature modeling tree, feature type, and related shape defining elements. However, performing a purely manual feature-based solid model assessment by using such kinds of generic system command is in many cases a sensitive task, which can devolve into quite a convoluted and time-consuming process. Moreover, only one model can be analyzed at a time. There is, therefore, a risk of putting in place different sets of assessments for individual models which were actually created for one and the same exercise or course assignment, and thus, in fact, relate to the same set of learning goals and outcomes.

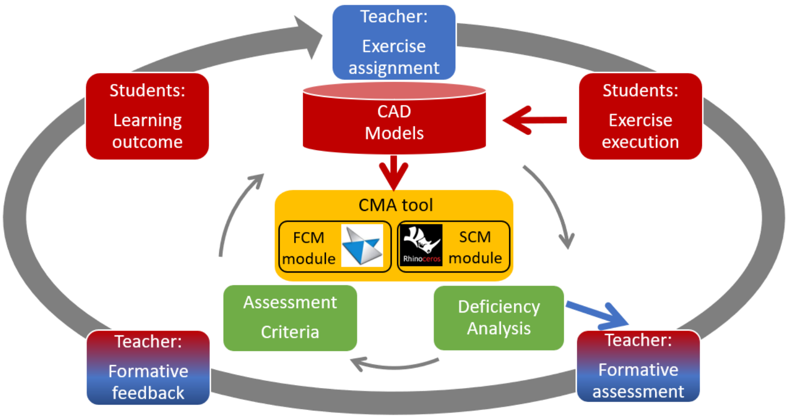

Fig. 1: Overview of structural components related to CMA tool, deficiency analysis, assessment criteria, and formative feedback within the newly developed integrated CAD course.

To support parametric feature-based solid model assessment, while avoiding the shortcomings as outlined, a software tool in the form of a module for feature-based CAD model assessment (FCM module) has been developed. The module will be combined with a module for surface CAD model assessment (SCM module, previously also developed by the authors) to form an integrated semi-automatic software tool for CAD model assessment (CMA tool, see again Fig. 1) that is aimed at supporting assessment of both feature-based solid models and surface models. The newly developed FCM module, introduced and outlined below, operates tasks in four process stages, namely compilation and export, import and filtering, enquiry and analysis, and visual analytics and assessment, as follows:

- All feature-based solid models that have been created by students are compiled and stored in a repository. This repository is structurally sub-divided into sets of different folders, with one set of folders for each exercise or course assignment. During the compilation process, information on feature entities and their related properties and meaningful characteristics, such as feature type, shape defining topology and geometry, is extracted from the parametric feature-based solid models, codified, and stored in the form of structured text files, with one file for each model.

- Data of parametric feature-based model entities and their properties/characteristics stored in the model repository are processed and imported into a CAD model inventory. This CAD model inventory provides a lattice-based data structure, which is structurally organized as various linked entity tables. Data compiled from CAD models associated with a particular exercise or course assignment are assigned to one particular cluster of entity tables. It should be noted that table entries for each feature entity in the model repository contain also an identifier-based link, which connects them to the geometric modeling system. This link mechanism allows for supporting human-based visual analytics and assessment of entities within the original data source, namely the CAD models in the modeling environment.

- To facilitate the computer-aided search and identification of deficiencies in feature-based CAD models, filter functions that are associated with the assessment criteria are provided at the user interface of the software tool. Those functions operate directly from the data of feature entities and their properties/characteristics, which were previously compiled and stored in the inventory. Note that the assessment criteria which are employed are related to the expected learning goals and outcomes of the individual exercises and course assignments.

- Final overall assessment, which still requires human intervention and expertise, is supported by the model entity analysis results obtained in the previous task and the cross-link structure outlined earlier. The latter enables entities of the repository and the inventory to be connected with their corresponding entities in the modeling environment. Hence, each entity in question, and most importantly those found by the software tool to be deficient, can be located in the original CAD model and made visible for further inspection and assessment by a human expert such as the course instructor or the academic supervisor.

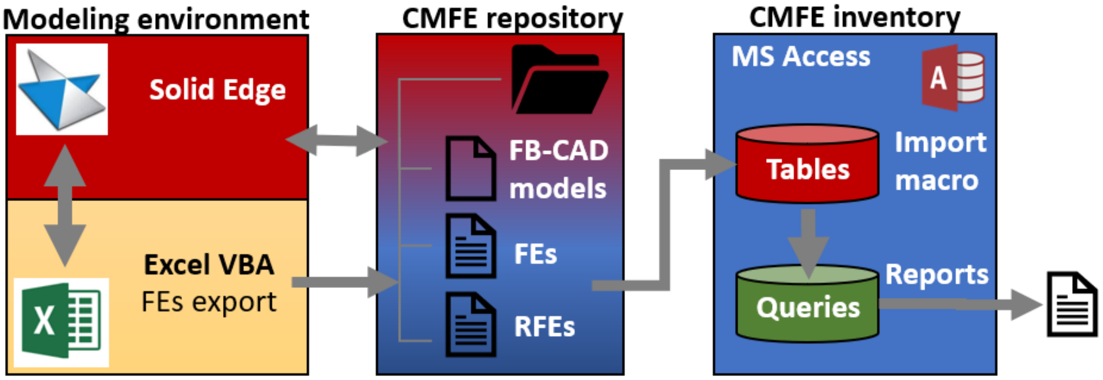

Fig. 2: Overview of technical architecture of the software tool.

To facilitate integration with previous work of the authors on software assessment tool development (cf. [8]), the software tool design is based on a modular open system structure (MOSS), which operates through the CAD model and feature entity (CMFE) repository that in turn facilitates not only the import from and export to different parametric feature-based solid modeling environments, but also sets of linked feature entities (FEs) and reference feature entities (RFEs) used to identify deficient feature entities. Within the CAD model feature entity (CMFE) inventory, those are then compiled together with results into the model entity analysis reports. The newly developed software tool features a technical architecture that leverages API-based functionality provided by commercially available CAD systems to support a modular and highly cohesive system architecture as shown in Fig.

2. Within the current implementation, the modeling environment deploys a commercially available parametric feature-based solid modeling system, namely *SolidEdge* from Siemens AG. At present, the import/export modules are implemented within the CAD modeling environment as procedures and functions based on Visual Basic for Applications (VBA), and within the CMFE inventory as Microsoft *Access* macros. The CMFE inventory itself is implemented and administered using the Microsoft *Access* relational database management system (RDBMS). Assessment criteria used for the CAD model deficiency analysis are specified and implemented using domain-specific Structured Query Language (SQL) expressions, predicates, and queries.

Conclusions:

The approach, structures, and technical architecture developed and used for the design and implementation of a novel software tool have been outlined and discussed. The work presented is aimed at supporting a learning outcomes-oriented assessment of parametric feature-based solid models within the context of CAD education. The current prototype implementation of the module-based software tool has been successfully tested and evaluated using CAD models that were submitted by students as results of CAD laboratory exercises and course assignments administered within a recently reformed CAD course in mechanical engineering, which is offered by the department where the authors operate. The software tool evaluation and its application in the assessment of parametric feature-based solid models covered all learning goal groups and related learning outcomes as stipulated for the course work. Based on the promising results of the experimental prototype system evaluation, preparations are under way to fully integrate the newly developed FCM module with the SCM module and deploy the entire CMA software tool within the CAD course in the coming academic year. This step is expected to commence fully integrated computer-aided support for formative assessment and formative feedback for both parametric feature-based solid models and three-dimensional surface models.

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