Title:
Surface Model Deficiency Identification to Support Learning Outcomes Assessment in CAD Education

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Introduction:
Recently, endeavors have been increasing to introduce and bring about changes in the way course curricula and teaching are designed and executed in education, particularly in science and engineering at institutions of higher education. These changes appear to be influenced as well as driven by two principal forces stemming from changes in a progressively technology-influenced postmodern society with its complex global labor market and from the results of work in educational research and cognitive science on how students learn. This situation is intensified by peremptory concerns related to the increasing gap between student learning outcomes that are achieved with classic, though apparently outdated, teaching approaches in higher education and the vigorously rising demand for professionals with sophisticated skills and competencies in highly competitive markets. In the context of computer-aided design and product modeling, this translates, according to trends and studies, into a focus on the development and implementation of restructured curricula and alternative teaching approaches. Such approaches need to be more student centered and learning oriented, and thus better structured to efficiently and effectively match actual student learning outcomes with skills and competencies related to, among other skills, spatial ability and mental visualization, cognitive model composition, meta-cognitive processes including planning, predicting, and revision, and modeling strategies (see also [1,10]).

These challenges, in regard to improved alternative teaching approaches, were addressed and tackled within discipline-based educational research from several directions as reported and discussed, for example, in [2,7,8,9]. 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, 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 three-dimensional CAD models created with parametric history-based solid modeling systems (cf. discussions and tool reviews in [3,4]).

Scope and Objectives:

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 the field of hybrid geometric modeling (cf. [8]). 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.

As the concept of a *usable* model is highly context-dependent, this matter can be approached from different dimensions and at various levels of abstraction. Within the work presented in this paper, three hierarchically structured levels related to current computer-aided product development processes have been identified, namely the geometric level, the analysis level, and the functional level. At the geometric level, a model is considered usable if it does not contain any severe geometric defects or spatial anomalies, which could impede the role of the model for being used in further steps of the modeling process. For example, the shape of a model is considered usable at the geometric level if its geometry is free of geometric deficiencies such as self-intersecting surfaces. At the analysis level, a model is considered usable if it meets all the requirements necessary to perform a particular model analysis. For example, a model can be considered usable when its shape is sound and structured so as to allow for the conducting of a finite element mesh analysis or a computer-aided engineering analysis. At the functional level, a model is considered usable if it meets all the requirements for the manufacturability, assemblability, and functioning of an individual component or assembly that its geometric representation was designed for and which is now being implemented. For example, the shape of a model is considered usable at the functional level if it allows for injection molding production. For any model to be considered usable at a particular level, a necessary pre-condition is that it is considered usable at the geometric level. Due to the fact that the CAD course, at present, is provided mostly to students who are novices in both geometric modeling and engineering, issues of model usability are currently approached from within spatial composition and shape, namely at the geometric level.

Within this educational setting, as outlined above, to facilitate actual implementation and improvement of the scope and overall quality of formative assessment and feedback, 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 requires new approaches and tools for surface model assessment. The aim of the current paper is, firstly, to present a novel approach to surface 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 surface model assessment approach.

Motivation, Approach and Implementation:

As indicated earlier, analysis and assessment of CAD models within the context of education are different from their counterparts in commercial and industrial settings in regard to goal and assessment criteria definitions, and thus to the approach taken. This is most evident within formative assessment, while also resonating within summative assessment. To support formative feedback in education, CAD 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 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 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 structural outline in Fig. 1). However, in the context of surface model assessment, analysis and evaluation are mostly based on the topology and geometry of the final modeling result. At the same time, the characteristics of individual curves and patches which 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 provide interactive commands at the user interface to allow for some basic form of inquiry about model properties and the characteristics of geometric model entities such as model closure and curvature graphs. However, performing a purely manual surface 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.

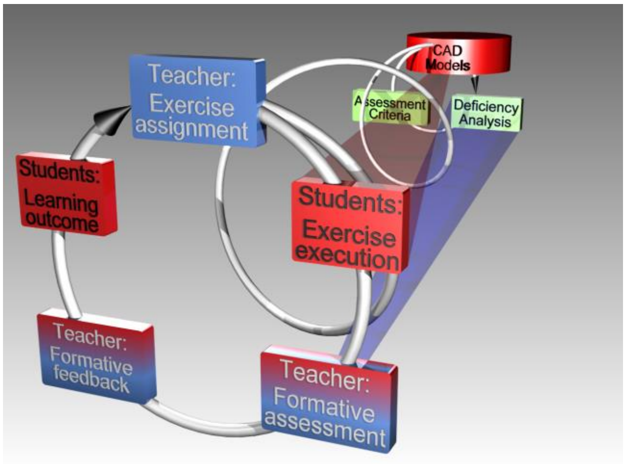

Fig. 1: Structural outline of the integration of computer-aided deficiency analysis with formative assessment and formative feedback.

In order to support surface model assessment, while avoiding the shortcomings as outlined, a semi-automatic software tool has been developed that operates tasks in four process stages, namely compilation and export, import and filtering, enquiry and analysis, and visual analytics and assessment, as follows:

- All surface 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 geometric entities and their related meaningful characteristics, such as entity degree, number of control points, and curvature radius, is extracted from the surface models, codified, and stored in the form of text files, with one file for each model.

- Data of geometric model entities and their characteristics stored in the model repository are processed and imported into a CAD model inventory. This CAD model inventory features 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 geometric entity in the model repository contain a unique entity identifier, which is also used internally by the geometric modeling system. This permits a backtrack mechanism to be utilized to support 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 surface-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 geometric entities and their characteristics, which were previously compiled and stored in the inventory. 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 backtrack function, along with the model entity analysis results obtained in the previous task. 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.

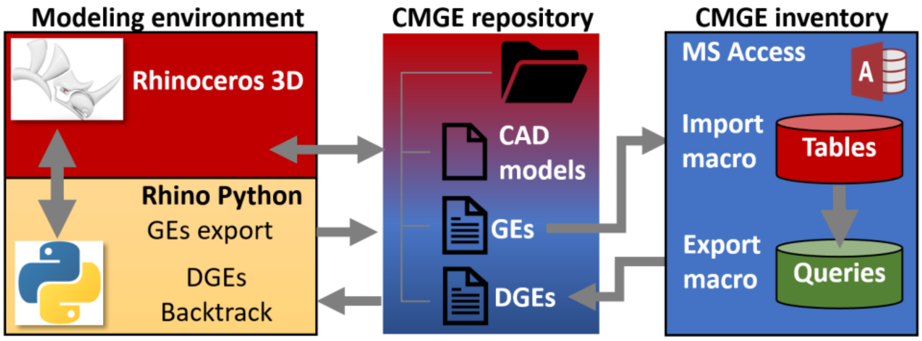

Fig. 2: Overview of technical architecture of the software tool.

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. The overall software tool design is based on a modular open system structure (MOSS), which operates through the CAD model and geometric entity (CMGE) repository that in turn facilitates not only the import from and export to different 3D surface modeling environments, but also backtracking of deficient geometric entities (DGEs). Within the current implementation, the latter deploys a commercially available NURBS-based surface modeling system in the mid range, namely *Rhinoceros 3D* from Robert McNeel & Associates. At present, the import/export modules are implemented within the CAD modeling environment as a Python Script, and within the CMGE inventory as Microsoft *Access* macros. The CMGE inventory itself is implemented and administered using the Microsoft *Access* database system. Assessment criteria used for the CAD model deficiency analysis are specified and implemented using SQL queries.

The current prototype implementation of the software tool has been successfully tested and evaluated using a set of 464 CAD models compiled into a CMGE repository of 33,189 geometric entities. The CAD models were submitted by students as results of CAD laboratory exercises and course assignments administered within a CAD course which was offered in the previous academic year by the department where the authors operate. The software tool evaluation and its application in the assessment of surface models covered all learning goal groups and related learning outcomes as stipulated for the course work.

Conclusions:

This paper has outlined and discussed the approach, structures, and technical architecture developed and used for the design and implementation of a novel software tool aimed at supporting a learning outcomes-oriented assessment of three-dimensional surface models within the context of CAD education.

The modular open system structure of the software tool, as developed and implemented, allows for an unobtrusive CAD model assessment that neither alters nor compromises in any way the original CAD models. Moreover, after the CMGE repository has been compiled, computer-aided assessment can be performed as many times as deemed necessary without requiring actual access to the original CAD models subject to assessment. These features, among others, not only afford both interactive and batch processing, but also allow for distributed and shared model assessment through the provision of controlled remote access to the repository. Since the formulation of the model assessment criteria, as designed and used in the software tool, is independent of the hardware and software platforms employed within the CAD modeling environment, the latest versions of the CAD hardware and software platforms can be used for the benefit of education and course work, while avoiding any impact on the actual model assessment criteria as implemented. Modification of the latter is required only if changes in the course-specific learning goals become necessary, which then also most likely propagate as changes required in the exercises and/or course assignments. However, should technical compatibility issues arise due to the use of newly available CAD hardware and software platforms, modifications are limited to the export/import module interfacing the CAD modeling environment with the CMGE repository. Based on the results of the experimental prototype system evaluation, preparations are under way to fully integrate and deploy the software tool in the coming academic year to support formative assessment and formative feedback within the recently reformed CAD course in mechanical engineering.

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