Title:
Improving the Learning Experience within MCAD Education: A Tool for Students to Assist in Self-Assessment during Modeling Exercises

Authors:
Ferruccio Mandorli, f.mandorli@univpm.it, Polytechnic University of Marche
Harald E. Otto, h.e.otto@univpm.it, Polytechnic University of Marche

Keywords:
Reflection on Performance and Outcome, Dormant Deficiency, Formative Feedback, Skill and Competency Development, CAD Model Alterability and Associativity

DOI: 10.14733/cadconfP.2021.149-153

Introduction:
Current developments and recent work in educational research have been aimed at creating awareness of and addressing the most prominent shortcomings and failures of current CAD education, in particular at institutions of higher education. Such efforts have provided new insights and recommendations, although the work is still limited and the results sometimes contradictory. Obviously, there is 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 demand 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. This requires, among other factors, a high-quality learning experience during frequent educational exercises in the CAD laboratory, providing opportunities for students to experience both design and creation of their own CAD models and the re-design and alteration of them. This also includes promoting good design practice by relating CAD model attributes and parameters to part functionality and design intent, which, in turn, depends on the restructuring of curricula. Current efforts are aimed at designing alternative teaching approaches and integrating suitable elements of those into CAD education so that it is transformed into a more student-centered, learning-oriented and practice-oriented system. 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, revision, and, most importantly, self-assessment and self-regulation (cf. [9,11,12]).

However, translating the potential and benefit of those encouraging ideas and plans into educational practice also requires better structured and more frequent assessment and feedback than can be achieved with traditionally employed assessment and feedback techniques. This, in turn, requires the provision of a means for students to actively engage in having more frequent feedback to support self-assessment, thus giving them more ownership and responsibility regarding the learning process and the actual outcomes achieved. Unfortunately, within CAD education, dedicated techniques and student tools are not yet available to support the implementation of enhanced learning experiences that support the learner's efforts at self-assessment through more frequent and timely feedback, and, in particular, within the context outlined earlier, to assist students in both the assessment of the CAD models they produced and the recognition of and learning from mistakes committed.

Scope and Objectives:

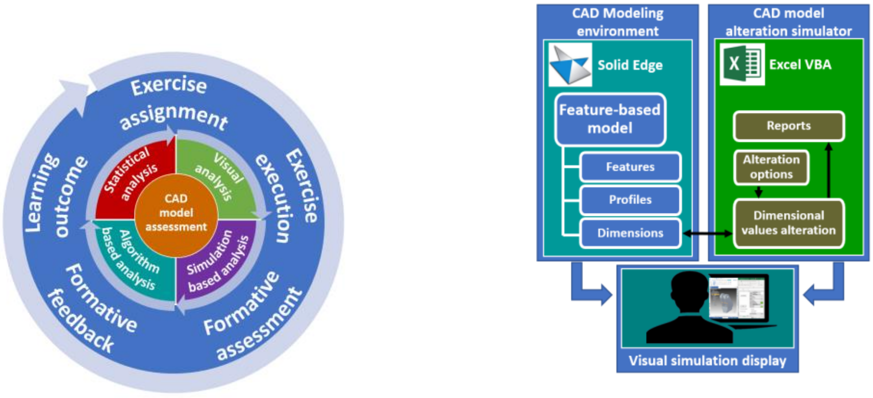
The basic goal and purpose of any learning experience are seated in acquiring the skills, knowledge, and competency to change and improve an existing behavior or create a new one. Those changes in behavior should have measurable impacts that relate to key metrics indicating success in achieving the desired learning outcome. Within the context of CAD education, those metrics are in most cases directly linked to the assessment criteria of CAD models created by students and submitted to teachers for grading. This approach has several shortcomings. Firstly, feedback is usually delayed due to the complexity of CAD model assessment and the rapidly increasing number of students in CAD courses at institutions of higher education. Secondly, the structure and quality of feedback based exclusively on CAD model grading is usually not sufficient to support learning from errors and developing metacognitive skills related to self-assessment, and subsequently self-improvement. Thirdly, feedback based on grading is applicable only to the final outcome, that is CAD models being created and remodeled until they reach a finished version that is deemed by students to be ready for grading by teachers. Hereby, the process of learning from errors, reflecting on mistakes committed, and trying out alternative solutions based on newly-gained understanding and improved skills, is somewhat short-circuited, and thus considerably reduced in its potential for the learner.

Recent approaches to the automation of CAD model grading are obviously capable of considerably reducing the time required for analyzing and assessing CAD models created by students, though the type and complexity of CAD model that can be analyzed, as well as the quality of feedback that is being generated, are still quite limited. Efforts to allow students to use the same software tools as teachers use for grading CAD models suffer not only from the limitations outlined, but also from the methodological and conceptual approach, because grading, as traditionally practiced within the educational context, provides feedback that is based on a finalized result, and thus always contains one assessment criterion that is related to the completeness of a solution. Being structured in this manner, it cannot be a direct part of the process and learning experience during the performance itself, that is the design, creation, and alteration of a CAD model. Examples of these recent approaches, related empirical studies, and further discussions can be found in [1,3,4,6,7,8]. The issues outlined earlier led the authors to initiate a two-step project. The objective of the first step of the two-step project is the design, development, and preliminary testing of a software tool aimed at supporting the identification of dormant deficiencies and critical situations. The objective of the second step is to provide the tool to all the students of the current CAD course, in order to improve their learning experience and to assist in self-assessment during modeling exercises. The aim of the present paper is to present important elements of, and results achieved within, the first step of the two-step project, as follows. Firstly, this paper presents an approach aimed at improving the development of skills and expertise in regard to robust and alterable parametric feature-based solid model creation. It attempts to achieve this by systematically analyzing and enhancing the learning experience during exercises related to CAD laboratory and course assignments. Secondly, the paper reports on the concrete development of a novel key metric used for CAD model analysis. This metric can represent success, but it can also identify core student behaviors that prevent the metric from being attained. Thirdly, the paper presents and discusses the development and implementation of a software tool designed for students and learners, to enable and support the putting into practice of certain components of this learning experience.

Approach, Development and Implementation:

Efforts were made to further reduce the gap between actual student learning outcomes as achieved and learning goals as pre-assigned within the CAD course, which is currently a part of the curriculum for the Laurea degree in mechanical engineering at the institution represented by the authors. These efforts resulted in a systematic approach being adopted in order to enhance the learning experience, in particular during exercise performance related to CAD laboratory and course assignments. This approach is structured according to the elements of learning and user experience design, and it also includes some backward-working segments between individual stages such as analysis and design (cf. [2,5,10]). Those main elements, and the stages used within the approach taken, can be outlined as follows.

At this point, we should recall the main objective of the learning experience subject to design and development, which is to create robust and alterable feature-based CAD models. For this purpose, a key metric, in the form of so-called *dormant deficiencies*, has been formulated and developed. This key metric has been designed not only to represent a measure of success, but also as a supporting concept to aid learning and to assist in understanding the central ideas and domain concepts of CAD model alterability and associativity. Then, based on this key metric and working backwards, the core behaviors that support the attainment of this metric have been determined as follows. Students need to be able to recognize critical situations, during modeling, which might result in dormant deficiencies. They also need to know what not to do, so that they can avoid dormant deficiencies being introduced into the CAD model, and they need to know how to properly define profiles and sketches, along with their related dimensions, in a manner consistent with the design intent and functionality of the part subject to modeling in the CAD environment.



(a) (b)

Fig. 1: Analysis approaches and technical architecture. From left to right: (a) overview of analysis approaches related to CAD model assessment and feedback within the recently restructured integrated CAD course, (b) overview of technical architecture of the student software tool.

Next, necessary knowledge, skills, and resources required for enabling and supporting those core behaviors were determined. They include, for example, defining effective associations, which is a skill built upon the knowledge of what makes certain dependencies and constraints effective, and which others are most likely to result in dormant deficiencies, and thus are better avoided. Knowing how to accurately create associativity is a knowledge-based task requiring a certain amount of practice. Here, within the context outlined earlier, students need to experience what it means and looks like to actually be able to create an alterable feature-based CAD model. This requires resources that allow students to systematically engage in self-assessment regarding the quality of the outcomes achieved during exercises, that is the CAD models created and the understanding and skills developed and improved. This in turn, requires some assistance, and that assistance needs to provide both an experience that brings some phenomena of important concepts to life and a means to help assess the CAD models in regard to the key metric. Based on those requirements, a novel software tool has been developed that enables students to assess a parametric feature-based CAD model in relation to its dormant deficiencies. This software tool also provides an experience of dormant deficiencies by visually demonstrating in real time the effects that those deficiencies can have on a CAD model, if they are activated during model alteration.

The software tool is based on the approach of an alteration simulator operating on the parametric structure of feature-based solid models. It is conceptually integrated with the current CAD course structure and resources in regard to CAD model assessment and feedback, as shown in Fig. 1(a). The software tool has a modular structure with a technical architecture as shown in Fig. 1(b). The simulation process is controlled by the user through an interactive user interface, which is provided within the dashboard of the software tool as shown in Fig. 2. The feedback generated by the software tool is provided in two modes. One mode is interactive, with feedback provided in real time. The CAD model and its shape are shown being modified and recreated within the CAD modeling environment during the simulated CAD model alteration. The other mode is static, with feedback provided in the form of a structured report that contains general information such as the number of features with profiles not fully constrained. Information is provided in the form of linked lists detailing critical situations that were encountered during the simulation. This second mode is structured to enable the student to systematically reflect on the mistakes that led to deficiencies in the CAD model. In particular, it provides information that supports the development of understanding of and insight into what went wrong during model alteration, where undesired changes and errors in the form of invalid features, and flawed or incorrect model geometry, occurred as a result of dormant deficiencies. The student can then consider the possible causes of these deficiencies.

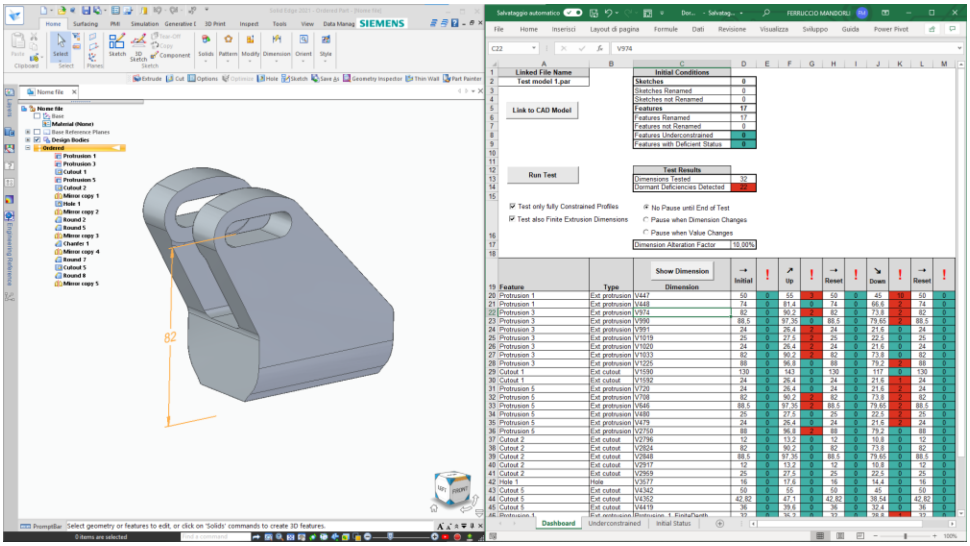


Fig. 2: Example of the visual simulation display offering a cross-linked view in real time during simulation and visual analysis.

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. 1(b). 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 simulator module and the assessment criteria used for the CAD model deficiency analysis are implemented within the CAD modeling environment as procedures and functions based on Visual Basic for Applications (VBA). The computation and interface structures of the assessment report and the dashboard of the simulator module are implemented within Microsoft *Excel* using VBA functions and procedures. Functionality and reliability tests have been successfully conducted with prototype and finalized versions of the implemented software tool. During the software tool tests, simulations were carried out on a wide selection of parametric feature-based CAD models that had been created and submitted by students during exercises related to CAD laboratory and course assignments in the last academic year. Formative usability testing has also been carried out with two groups of student volunteers who previously attended the course. These studies into usability and effectiveness not only provided insight on improvements that could be put into action right away, but also revealed what student users like and what works best for them.

Conclusions:

The approach, framework, and structures designed and used for the development of a novel software tool for students have been outlined and discussed. The work presented is aimed at improving the learning experience within the context of CAD education. In particular, it attempts to support the self-assessment and self-adjustment efforts of students, along with offering a better way to make sense of experience and domain knowledge while practicing the design and creation of robust, alterable parametric feature-based solid models. The current implementation of the software tool has been successfully tested and evaluated using CAD models that had been 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. Currently, preparations are under way for the second step of the two-step project. This second step aims to fully integrate the newly developed student software tool within the CAD course and to deploy it in the coming academic year. These efforts will include a systematic introduction during the course lessons, a multimedia-based online tutorial, and an online survey based on questionnaires. The questionnaires are structured so as to gain insight based on feedback from the students' perspectives on what worked and what did not. They will also indicate any further learner needs that have been overlooked and give guidance as to how the tool can be improved and its use expanded, and how it can be introduced smoothly into the CAD course.

References:

[1] Ault, H. K.; Fraser, A.: A comparison of manual vs. online grading for solid models, in: Proceedings of the 120th ASEE Annual Conference and Exposition, June 23-26, Atlanta, GA, USA, 2013, Paper-No.: 7233. https://doi.org/10.18260/1-2--19045

[2] Branch, R. M.: Instructional Design: The ADDIE Approach, Springer, New York, NY, USA, 2009. http://dx.doi.org/10.1007/978-0-387-09506-6

[3] Bryan, J. A.: Automatic grading software for 2D CAD files, Computer Applications in Engineering Education, 28(1), 2020, 51–61. https://doi.org/10.1002/cae.22174

[4] Garland, A. P.; Grigg, S. J.: Evaluation of humans and software for grading in an engineering 3D CAD course, in: Proceedings of the 126th ASEE Annual Conference and Exposition, June 16-19, Tampa, FL, USA, 2019, Paper-No.: 26525. https://doi.org/10.18260/1-2--32764

[5] Garrett, J. J.: The Elements of User Experience, Peachpit (Pearson Education Division), Berkeley, CA, USA, 2011. https://dl.acm.org/doi/10.5555/1965524

[6] Gonzáles-Lluch, C.; Company, P.; Contero, M.; Pérez-López, D.; Camba, J. D.: On the effects of the fix geometric constraint in 2D profiles on the reusability of parametric 3D CAD models, International Journal of Technology and Design Education, 29, 2019, 821 - 841. https://doi.org/10.1007/s10798-018-9458-z

[7] Ingale, S.; Anirudh, S.; Bairaktarova, D.: CAD platform independent software for automatic grading of technical drawings, in: ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, August 6 – 9, Cleveland, OH, USA, 2017, Paper-No.: DETC2017-67612. https://doi.org/10.1115/DETC2017-67612

[8] Kirstukas, S. J.: Development and evaluation of a computer program to assess student CAD models, in: Proceedings of the 123rd ASEE Annual Conference and Exposition, June 26-29, New Orleans, LA, USA, 2016, Paper-No.: 15834. https://doi.org/10.18260/p.26781

[9] Pütz, C.: Teaching CAD with a pedagogical system ranging from videos to individual tutoring, Journal of Industrial Design and Engineering Graphics, 12 (1), 2017, 21–26.

[10] Wiggins, G.; McTighe J.: Understanding by Design, Association for Supervision and Curriculum Development (ASCD), Alexandria, VA, USA, 2005.

[11] Wong, Y. L.; Siu, K. W. M.: Assessing Computer-Aided Design Skills, in: Khosrow-Pour, M. (ed.), Encyclopedia of Information Science and Technology, IGI Global, Hershey, PA, USA, 2018, Volume 10, 7382-7391. https://doi.org/10.4018/978-1-5225-2255-3.ch642

[12] Yan, C.; Yu, B.; Hui, Y.; Zhou, F.: CAD education of college students with engineering practice and team work, EURASIA Journal of Mathematics, Science, and Technology Education, 13(7), 2017, 5569-5576. https://doi.org/10.12973/eurasia.2017.01010a