# Improving the Learning Experience within MCAD Education: The Provision of Feedback on CAD Model Quality and Dormant Deficiency in Real-Time

Ferruccio Mandorli[1] and Harald E. Otto[2]

[1]Polytechnic University of Marche, f.mandorli@univpm.it
[2]Polytechnic University of Marche, h.e.otto@univpm.it

Corresponding author: Ferruccio Mandorli, f.mandorli@univpm.it

**Abstract.** Formative assessment is an important element for supporting any learning process, with the provision of feedback being one of its most effective strategies. However, despite the extensive body of research on feedback and its importance to learning, its effectiveness and usefulness, and thus its expected effect, are not always guaranteed. This, in part, can be attributed to issues concerning how students make sense of and act upon feedback and the gap between how students receive and perceive feedback and how teachers structure and provide it. After the introduction of a newly developed feedback intervention aimed at improving the learning experience and, consequently, performance outcomes, it is now time to determine the next steps. This requires insight into and understanding of the usefulness and effectiveness of the recently introduced educational intervention, and this insight should be based on empirical evidence. This paper reports on the first part of an empirical study organized as a two-part project aimed at determining to what extent the new feedback intervention has had a positive impact on the learning experience and outcomes. The study also aims to determine the effect sizes and their relationships, along with the impact of the feedback characteristics on the goals in relation to the complex task of creating robust and best practice-compliant CAD models.

**Keywords:** Feedback effects, skill and competency development, CAD model alterability, dormant deficiency, design intent.
**DOI:** https://doi.org/10.14733/cadaps.2024.739-758

## 1 INTRODUCTION

The potential of feedback for improving performance and enhancing learning outcomes is widely acknowledged in most fields and disciplines. In particular, feedback within formative assessment is considered by many experts to be a crucial element of appraisal and evaluation in the learning process. However, due to the complexity of the learning processes and several variables that moderate the effectiveness of feedback and its means of implementation, understanding the workings of and deriving generalizations based on empirical evidence from this powerful educational intervention still poses a challenge. This is even more so if one takes into account the recent trend of progressively expanding the use of computer-based learning environments and blended course learning. In such cases, feedback provision is increasingly autonomous and it is invoked as well as driven by the interaction of students with a computerized learning environment. During the restructuring of a CAD course for mechanical engineering (MCAD), after a promising pilot run, an interactive feedback intervention was introduced, together with other educational measures, through a computer-based agent in the form of a software tool. To obtain a better insight into the effect of this feedback intervention and how it was received, rated, and actually used by students, a two-part study was conducted analyzing empirical data relating to the viewpoints of students and the teacher. In this paper results and findings pertaining to this study are presented and discussed.

## 2 BACKGROUND, SCOPE, AND OBJECTIVES

### 2.1 Background and Related Work

Formative assessment is an important element for supporting any learning process, with the provision of feedback being one of its most effective strategies. Depending on the form and approach to feedback provision, feedback can be classified into various types. Focusing on the point in time of the provision, feedback can be provided while work is still in progress, which is referred to as forward-looking. On the other hand, feedback can be provided in regard to some final outcome a student has produced, which is usually referred to as backward-looking. This classification relates to the three basic aims of effective feedback: guiding students through indicating what the learning goals are, determining what progress has been achieved toward those goals, and deciding what action is required to further progress (see also discussions on feed up, feedback, and feed-forward in [33]). Notice that this three-aims structure of feedback also corresponds to and aligns to some extent with the three-processes structure relating to formative assessment identified and discussed in [8]. Further approaches to the classification of feedback that are often found in the literature are based on the information/knowledge structure and the response/revision structure of feedback. In the case of the former, general types of feedback are identified as *corrective feedback*, referred to as *knowledge of response* and *knowledge of the correct response*, and *elaborative feedback* or *high-information feedback* (cf. [17,65]). As was discussed in [3,17,31,63], corrective feedback is somewhat limited as it has only a corrective function. However, elaborative feedback and high-information feedback are able to go beyond the limits of corrective functions, as they also contain information relating to the task, process, and level of self-regulation (see discussions in [3,63,65]). Thus, they are more effective for higher-order learning and skill development. Another feedback classification can be found in [41]. Here, corrective feedback relates to how well a student's outcome and performance align with an assignment. Feedback that prompts deeper thought and challenges the student to delve deeper into particular ideas is referred to as *epistemic feedback*. Another type, referred to as *suggestive feedback*, provides both advice on how to improve and ideas for possible expansions. The combination of epistemic and suggestive feedback not only prompts students to offer further clarification but also provides specific suggestions. Note that these types of feedback are not mutually exclusive, as elements of various types are most likely contained in the actual feedback interventions, depending on the assignments and learning goals.

Another important factor to be considered is the level at which feedback works. According to the feedback model described in [31], feedback can work at four levels, namely the task level, the process level, the self-regulation level, and the self-level. The last of these, pertaining as it does to personal evaluations, is somewhat questionable, as it has only a minimal effect, and it can even affect learning negatively (cf. [31,39]). As feedback is effective only when it can be processed by the learner to facilitate improvements in development, it requires information on the gap between current and reference performance. At this stage, therefore, information at the task and process levels is the most vital, while information pertaining to the self-regulation level can be considered supportive to a varying degree, depending on the nature of the learning environment and context.

For feedback to be effective and successful as an educational intervention, it needs to meet certain requirements, which can be expressed through the following characteristics. Firstly, to avoid overwhelming students, any feedback should be targeted and concise to help in directing attention to the core areas where progress needs to be made. Secondly, to align feedback with the goals of assignments and exercises, it should be focused. This helps to prioritize not only the main areas of importance but also the efforts required. In this regard, work described, for example, in [18,21,42] showed that another factor in providing concise and focused feedback is the degree of personalization. Personalized feedback helps students to stay motivated, supports self-regulation, and is unanimously favored over more general feedback in many learning situations. Thirdly, to adequately guide students in their efforts to revise and develop their knowledge and skills, feedback should be action-oriented and should point to specific areas during the learning process. Fourthly, to maximize the effect and usefulness of feedback, it should be timely and frequent, and it should allow students to engage with it (see also discussions on feedback frequency and multiple-try feedback in [52,60]). That is to say that the students must understand it, translate it into action toward improvement, and connect it with prior knowledge so that they can learn from it (cf. [48]). In respect to feedback engagement, a study reported in [20] showed that under a feedback provision where students owned the decision on whether or not to receive feedback, the commitment to and use of feedback was much higher.

Those feedback characteristics outlined above correspond closely to the four important conditions for useful and effective feedback as identified and put forward in [33,61], which can be summarized as follows. First, the student must be in a situation where feedback is needed. Second, the feedback must be provided in a timely manner. Third, the student must actually be willing and able to receive and use the feedback. Here the feedback is assumed to be appropriate to the learning and exercise task and to the student's disposition and needs. Fourth, the feedback should be related to the task itself rather than directed at the student (see also related discussions in [6,33,55]).

Despite the extensive body of research on feedback and its importance to learning, its effectiveness and usefulness, and thus its expected effect, are not always guaranteed. This, in part, can be attributed to issues concerning how students make sense of and act upon feedback (see also [19,54]) and the gap between how students receive and perceive feedback and how teachers structure and provide it (cf. [13,47]). Even in cases where the feedback meets most of the criteria outlined earlier, its actual effect still depends on how students recognize and understand it, and eventually use it (cf. [14]). In this regard, research on assessment literacy, meaning the ability to understand and properly use feedback, as reported in [22,58], and studies on empowering students to recognize feedback (see also discussions in [9,56,57]) are valuable contributions. These studies support the suggestion that a shift is required from the view that teachers should control feedback exclusively towards the idea of an assessment and feedback process that engages students more meaningfully while also helping in the development of student self-assessment and self-regulation.

Within the context of MCAD education, one of the recent trends outlined above is feedback intervention based on computerized approaches such as software tool agents oriented toward the automation of CAD model grading. However, as these computerized approaches are still in their infancy, the type and complexity of CAD models that can be analyzed, and the quality of the feedback that is generated, are still quite limited. Moreover, the concept that students should be able to use the same software tools as those which teachers use to grade CAD models produces further difficulties. Not only is there a limited feedback structure, but also, from the methodological and conceptual approach, grading, as traditionally practiced within the educational context, provides feedback that is based on a final result (see also backward-looking feedback discussed elsewhere in this paper), and thus it 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 recent approaches for technical drawings and 2D CAD files can be found in [12,35]. Results and examples of recent approaches for 3D CAD models and related empirical studies are reported in [4,29,38]. An interesting approach to providing visual feedback for automated CAD model grading using heat maps is reported in [37]. Further discussions on the subject of automated CAD model grading, including a summary of the literature and pointers to gaps in research, can be found in [26].

## 2.2 Scope and Objectives

As research and countless studies on the effectiveness and usefulness of feedback interventions have demonstrated, educational intervention is complex, and does not always guarantee the pedagogical success expected, but in many cases – when following all the guidelines and best practices on how to structure and provide it – it stands a fair chance of having a significant positive effect on learning and performance outcomes. 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.

As outlined earlier, most software tools supporting automated grading and assessment of CAD models that are currently provided to students in CAD courses at institutions of higher education 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 (see again backward-looking feedback, as discussed elsewhere in this paper). 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 re-creation 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. This, in turn, prevents them from providing any forward-looking feedback, which is essential to support the learning process while moving forward and indicating what progress is being made toward the goal.

The newly developed feedback intervention includes, among several other measures, a metric of dormant deficiencies, which is a dynamic and more inclusive measure that takes into account the impact that alteration and the CAD model regeneration process have on the original modeling process and its outcome. It is, therefore, a more process-oriented and simulation-based assessment approach, and so those limits outlined above can be overcome in a straightforward manner, as described in detail in [45,51]. Additionally, implementation and provision of the feedback intervention have been oriented as closely as possible on what is known from research on effective and useful feedback. Now that the newly developed feedback has been administered within a restructured MCAD course (cf. [44]), the time has come to look into the empirical data to gain insight into whether this educational intervention was actually successful and to what extent it has a positive effect on student learning and outcomes. These, among other reasons, led the authors to initiate an empirical study organized as a two-part project. The objective of the first part is to determine to what extent the feedback intervention has had a positive impact on the learning experience and outcomes. If the intervention has, in fact, had such an impact, the study also aims to determine the effect sizes and their relationships, along with the impact of the feedback characteristics on the goals in relation to the complex task of creating robust and best practice-compliant CAD models. The objective of the second part of the two-part project is to shed more light on the effect and appropriateness of the feedback intervention from the student perspective. This is approached through an empirical study based on questionnaires and surveys, through which students can voice their thoughts and opinions, critique the restructured MCAD course, and, in particular, give their opinions regarding the learning experience and the recently introduced feedback intervention. The aim of the present paper is to present empirical data, results, and insight gained through the first part of the two-part project. Accordingly, the paper is structured as follows. First, in section 3, a brief overview is provided on the developmental approach to and the operationalization of the newly developed feedback intervention for MCAD education. Next, in section 4, details of the empirical study are presented in regard to the central research questions, the research design and method, the results of the CAD model analysis, and the effect size computations. This is followed by a discussion and a summary of the results and insights obtained so far through this study. Finally, in section 5, some conclusions are drawn and an outlook is given on research planned for the near future.

## 3 INTERACTIVE ELABORATIVE FEEDBACK INTERVENTION

### 3.1 Approach and Concepts

Efforts were made to reduce the gap between actual student learning 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 (cf. [11,27,64]). This requires, among other measures, more frequent formative feedback (see also discussions in [31,36]), which has led to the re-design of the learning experience for CAD modeling exercises, and that, in turn, has required the development of a novel CAD model assessment metric that can also be used as a key metric to evaluate core student behavior. These requirements have been addressed through a feedback intervention based on a software tool-driven feedback agent that has been designed specifically for the needs of students.

At this point, we should recall the main objective of the learning experience subject to design and development, which is to create best practice-compliant parametric feature-based CAD models that are robust and alterable. In support of the latter, a novel 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. This key metric is also a central part of the feedback intervention to provide information for forward-looking feedback and to indicate what progress is being made toward the learning goal. Dormant deficiencies can be conceptualized as errors in associativity, which were introduced during the modeling process by making mistakes in the specification of dependencies between geometric entities and features. However, the effect and impact of these mistakes on the CAD model remain dormant until an actual CAD model regeneration is triggered and executed through an alteration. In this context, the outcome in regard to deficiencies is related to which of three different error situations occurs. Accordingly, dormant deficiencies are classified as type I, type II, or type III. A type I dormant deficiency leads to deficiencies in features. The regenerated CAD model contains features which are labeled with a warning or failed status. This will result in a shape that is incomplete and / or incoherent. More details on the classification and theoretical foundation of dormant deficiencies, together with application examples, are reported in [44,51]. Note that for the empirical study reported in this paper, only type I dormant deficiency is considered. The nature and category of dependencies between geometric entities and features are determined, among other characteristics, by their range in regard to features and the class of features with which they are associated, that is, profile-based features or non-profile-based features. This results in intra-feature dependencies or inter-feature dependencies. Here, the former represents dependencies between geometric entities within one and the same feature, while the latter refers to dependencies between geometric entities of more than one feature. Note that, in the case of profile-based features, deficiencies within intra-feature dependency are most likely to be introduced during profile creation when associativity is created between the 2D geometric entities of the profile. In cases where the profile is comprised of a basic non-complex outline, the CAD system usually creates rudimentary geometric constraints automatically. However, in the case of complex profiles, the user is required to explicitly define all the constraints required.

## 3.2 Structure and Operationalization

Besides acquiring an understanding of and know-how related to the criteria associated with guidelines and best practice compliance, students also need to be able to recognize critical situations during modeling that might result in dormant deficiencies and need to know what not to do in order to avoid introducing dormant deficiencies into the CAD model. They also 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. Related to all this are the necessary knowledge, skills, and resources required to enable and support those core behaviors. These include, for example, defining effective associations, which is a skill built upon the knowledge of what makes certain dependencies and constraints effective and which ones 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 look 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 requires some assistance. Supported through the feedback intervention and the software tool, as well as the integrated CAD modeling environment, students can experience some phenomena that bring important concepts to life, and they are provided with a means to help assess their CAD models in regard to the key metric.

Requirements that were identified and taken into account for the design of supporting resources and the provision of feedback are as follows. First, one central requirement is to provide an experience that brings some phenomena of important domain concepts to life. Within the given context, this relates to the concepts of robustness and alterability of parametric feature-based CAD models and, consequently, to the concept of dormant deficiencies. Students need to experience first-hand during practical exercise work what it means to make mistakes during the creation of dependencies and thus introduce dormant deficiencies, resulting in CAD models that are neither robust nor alterable. They also need to see with their own eyes how those dormant deficiencies that they introduced during the modeling process can impact the CAD model they created in downstream processes and model reuse, requiring redesign, alteration, and CAD model re-creation. Of particular interest here are the structural and visual phenomena related to invalid features and invalid geometry that are produced by the CAD system during the regeneration of the CAD model after a parameter, such as a dimension value in a profile or feature, has been altered and has thus activated dormant deficiencies. Second, another central requirement is to provide a means for supporting CAD model assessment and elaborative feedback in regard to the key metric and all the criteria associated with the guidelines and best practices. Students should be able to run automated tests under various assessment scenarios to see if their models contain dormant deficiencies or not and to what extent their models are compliant with best practices. Those scenarios should allow for including / excluding fully constrained profiles and finite feature extrusion dimensions. Students should also be allowed to partially control feedback provision by setting breakpoints during the automated assessment process, so that they can investigate and study feedback and interim test results, stepwise and in detail. Third, because the feedback intervention is aimed at supporting formative self-directed assessment during exercise-based learning experiences, it is also important that CAD model assessment and feedback provision can be executed at any stage during the modeling / remodeling process. This is in stark contrast to automated grading tools generally used by teachers that can be applied only to final outcomes – thus permitting backward-looking feedback only. That is to say that such grading tools can be applied only to finished CAD models, to support a kind of summative assessment. Fourth, interactive elaborative feedback needs to be able to provide students with information and assistance in locating and analyzing mistakes committed earlier during the creation of dependencies. This is important to support reflection on, as well as learning from, errors. These are two important elements in the development of skills and expertise in regard to both knowing what not to do in certain situations in order to avoid mistakes and knowing what to do instead (see also [43,46,50] and discussions on the so-called *error generation effect* in [40]).

# 4 EMPIRICAL STUDY

## 4.1 Overview and Research Questions

The basic goal and purpose of any learning experience are to acquire the skills, knowledge, and competency to change and improve an existing behavior or to 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. Here, feedback intervention is one of the most powerful educational interventions, though there is a remarkable variability in its effects. The objective of the first part of this two-part study was to determine and better understand the effects of the newly introduced feedback intervention on student learning and performance from the teacher's perspective. In particular, the study presented in this paper addressed the following research questions:

**RQ1:** To what degree does feedback intervention in the form of a student software tool impact the learning experience as well as the outcome, and what are the feedback effects on student achievements in the context of creating robust and best practice compliant parametric feature-based CAD models?

**RQ2:** To what extent do the effects and characteristics of feedback pertain to goals related to CAD model creation, task complexity, and student performance challenges?

## 4.2 Research Design and Method

To avoid inefficiency through conducting an overpowered study that would require unnecessary expenditure of resources, particularly in the case of individual analysis of hundreds of feature-based CAD models to obtain the data required for the study, a power analysis was included to optimize the research design of the study. This was also meant as a precaution to avoid designing an underpowered study in which results were likely to be wrongly interpreted as evidence of the ineffectiveness of the feedback intervention, thus misleading further research.

A prior power analysis to estimate the required sample size $N$ contingent upon effect size estimate, alpha significance $\alpha$, and the desired power level of the test – referring to the type II error rate beta and defined through (1-$\beta$) – was conducted as follows. First, a lower-limit estimate for the effect size had to be determined. Here, in general, the effect size estimate needs to be of a value which, for any educational method or technology, can be taken seriously (see also discussions in [32]). It also needs to be well-placed within the effect size range argued to be relevant for any feedback intervention. From meta-analytically derived estimates (cf. [31,32,63,65]) it was determined that this study on interactive elaborative feedback in MCAD education should be capable of detecting at least a real effect that is about 0.45. Next, following the guidelines in the literature set forth initially by Cohen's 4:1 weighting of beta-to-alpha risk (cf.[16]) – which has become an informal standard as a good default that will be acceptable in many settings – and delimiting alpha significance to $\alpha$ = 0.05, values were set for beta levels at 0.20 and for power at 0.80. Finally, an estimate for the sample size $N$ was determined using these study power parameters and tabulated values for minimum sample sizes for different effect sizes and power levels, as provided in [23]. Sample sizes of suitable matches with the study power parameter settings outlined above were in the range of 160 to 170, allowing for the detection of actual effects as small as 0.446 to 0.432.

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 before the feedback intervention was introduced. The experimental set consisted of CAD models that were submitted by students after introduction of the feedback intervention. All CAD models used in the study were created as part of concrete exercise assignments and CAD laboratory activities, which are components of an actual CAD course for mechanical engineering at the institution where the authors operate. After initial model validity and data integrity checks and statistical power analysis, a total of $N$ = 166 (control $n$ = 74 / experimental $n$ = 92) student-created CAD models were deployed in the study. All CAD models that were deployed in the study were individually analyzed and assessed by the authors. Results obtained were then cross-checked to verify the accuracy, correctness, and integrity of the analysis and its outcome.

As the study is aimed at examining the nature and effectiveness of an educational feedback intervention, the outcome measure is categorized through two dichotomous variables with data organized in a four-fold table, which can be structured as a 2 x 2 matrix and denoted by $\boldsymbol{A}$ with $\boldsymbol{A} = (a_{ij})_{1\le i,j\le 2}$. This indicates the proportions of CAD models observed with a certain property before and after the feedback intervention falling in the row $i$ and column $j$, represented as raw frequency values of each respective entry of the matrix $\boldsymbol{A}$ denoted by $a_{ij}$. Here the most appropriate measure of effect size is the odds ratio or a transformation such as the natural logarithm of the odds ratio, denoted by $OR$ and $\ln(OR)$, respectively. The logarithms of the odds and the odds ratio are also referred to in the literature as the *logit*, and the log odds ratio, and *logistic difference* (cf. [5,10,25]). The odds ratio can be calculated as a cross-product ratio in the form of $OR = (a_{11}a_{22})/(a_{12}a_{21})$. Some of the key benefits of this effect measure for dichotomous data are that it is not affected by unequal sample sizes and that it is compatible with logistic regression and loglinear models. In addition, it is invariant when rows / columns are multiplied by a constant $\mu$ such that $(\mu\boldsymbol{A})_{i,j} = \mu\boldsymbol{A}_{i,j}$ and changed so that the rows become columns and vice versa, that is $(\boldsymbol{A}^{\mathrm{T}})_{i,j} = \boldsymbol{A}_{j,i}$. If the order of the rows or columns is reversed, the odds ratio is reversed, resulting in the reciprocal of the $OR$. Usually, odds ratios close to 1.0 represent a very small effect size due to $\ln(1) = 0$, which is interpreted as no effect. In the literature several methods can be found for calculating an approximate 95% confidence interval for the log odds ratio. For the study presented in this paper the Wald method (cf. [1]) has been used, because it provides an approximation to the 95% confidence interval that is considered reasonably accurate and sufficient for the research methodology and sample size used (see also discussions in [25,62]). This method is based on calculation of the standard error denoted by $SE$ of the logistic difference, that is, $SE(\ln(OR)) = (1/a_{11} + 1/a_{12} + 1/a_{21} + 1/a_{22})^{1/2}$. From this, lower and upper bounds for a 95% confidence interval denoted by $CIL$ and $CIU$ can be calculated as $CIL = \ln(OR) - z_{95\%}SE(\ln(OR))$ and $CIU = \ln(OR) + z_{95\%}SE(\ln(OR))$. Here for a 95% confidence level the critical value of the $z$-statistic is $z_{95\%} = 1.96$. As the log-scale is quite unintuitive, the 95% confidence interval of the odds ratio denoted by $CI$ is then presented by taking the anti-log, that is, $CI = [e^{CIL}, e^{CIU}]$ (cf. [1,34]). However, this confidence interval of the odds ratio is not symmetric about the point estimate $OR$ as it is in the case of the logistic difference. This is due to the odds ratio being skewed to the right as it can be only a non-negative number.

## 4.3 Analysis and Results

### *4.3.1 CAD model analysis and performance outcome*

Analysis and assessment of the feature-based CAD models created by students throughout a series of design and modeling exercises revealed a considerable improvement in the quality of those CAD models created by students who had been provided with an improved learning experience using software tool-based interactive feedback. Under this feedback intervention, the proportion of CAD models that contained features with warning/failure status was reduced from 13.51% to 5.43%. The proportion of CAD models that contained un-renamed features was reduced from 78.38% to 57.61%. However, the greatest improvement found during the analysis was in the proportion of CAD models that contained under-constrained features. Here the proportion was reduced from 21.62% to 5.43%, which represents a factor of about 4.

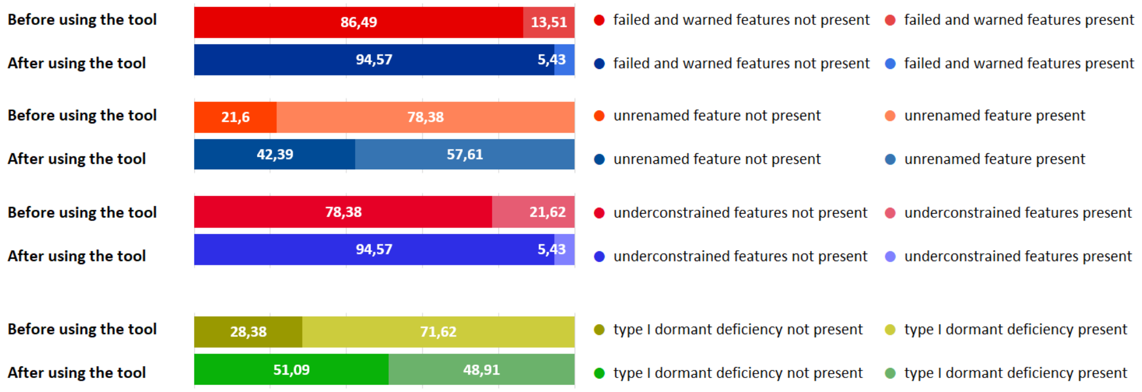


**Figure 1:** Graphical representation of proportions of CAD model deficiencies (before / after feedback intervention) in each of the main categories that are linked to assessment criteria and associated effect sizes.

Further improvements were found in regard to dormant deficiency, which considerably impacts CAD model alterability, and thus model robustness. Here the proportion of CAD models that contained type I dormant deficiencies was reduced from 71.62% to 48.91%. Figure 1 shows a graphical summary of the proportions of CAD model deficiencies which fall into each of the main categories that are linked to assessment criteria and associated effect sizes, as discussed throughout the CAD model analysis and assessment presented in this paper.

### *4.3.2 Feedback effects on compliance with best practices*

Based on the results of the CAD model analysis presented above, statistical significance and effect sizes for feedback intervention in each aspect of CAD model quality improvement – and thus improvement of the skills and competency required to create those more robust and best practice compliant models – were as follows.

In the case of CAD models that were not compliant with any criterion of the guidelines and best practices, that is, models that contained un-renamed and under-constrained features with warning / failure status (A1), the calculated individual odds yielded an odds ratio *OR* = 2.883 and an approximate 95% confidence interval *CI* = [1.410,5.897] with the approximate standard error of the log odds ratio *SE*(ln(*OR*)) = 0.3651. Thus, the overall odds that a CAD model would contain a deficiency as outlined were almost 2.9 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student with 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 ($df = 1$, $\chi^2 = 8.7409$, $p = 3.111\text{e-}3$), which also yields a statistically significant relationship at the 5% level between the presence or absence of deficient features and CAD models that were created without feedback intervention and those that were created with feedback intervention made available to students.

In the case of CAD models that contained features with warning/failure status (A2), the calculated individual odds yielded an odds ratio *OR* = 2.719 and an approximate 95% confidence interval *CI* = [0.886,8.341] with the approximate standard error of the log odds ratio *SE*(ln(*OR*)) = 0.5719. Thus, the overall odds that a CAD model would contain a deficiency that was related to a feature with warning/failure status were a little above 2.7 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student who had been provided with feedback intervention. Notice that the confidence interval of the odds ratio as reported above contains an odds ratio of 1, thus indicating that there was no statistically significant difference at the 5% level in the odds that a CAD model created by a student without feedback intervention would contain a feature with warning/failure status and that a CAD model created by a student who had been provided with feedback intervention would contain a feature with such status. However, the calculation of a more traditional measure, the chi-square statistic, indicates ($df = 1$, $\chi^2 = 3.2565$, $p = 7.114\text{e-}2$) that the results were not too distant from a statistically significant relationship at the 5% level. Therefore, we should not dismiss the practical significance of the feedback intervention and its effect size too quickly based on a single result obtained from a statistical viewpoint.

In the case of CAD models that contained un-renamed features (A3), the calculated individual odds yielded an odds ratio *OR* = 2.668 and an approximate 95% confidence interval *CI* = [1.337,5.323] with the approximate standard error of the log odds ratio *SE*(ln(*OR*)) = 0.3526. This means that the overall odds that a CAD model would contain a deficiency in the form of an un-renamed feature were a little below 2.7 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student with 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 ($df = 1$, $\chi^2 = 7.9855$, $p = 4.715\text{e-}3$), which also yields a statistically significant relationship at the 5% level between the presence or absence of un-renamed features and CAD models that were created without feedback intervention and those that were created with feedback intervention made available to students.

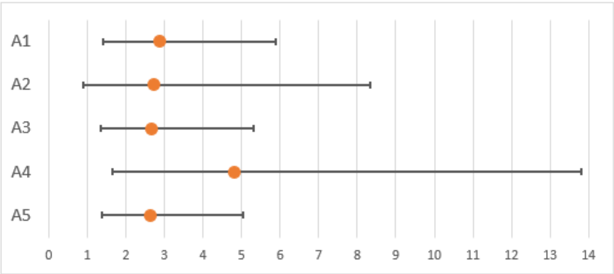


**Figure 2:** Graphical representation of odds ratios and associated confidence intervals.

As can be inferred from the CAD model analysis results above, the greatest effect size is in the case of CAD models that contain under-constrained features (A4). Here the calculated individual odds yielded an odds ratio $OR$ = 4.800 and a 95% confidence interval $CI$ = [1.667,13.823] with the approximate standard error of the log odds ratio $SE(\ln(OR))$ = 0.5396. Hence, the overall odds that a CAD model contained under-constrained features were 4.8 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student with feedback intervention available. Here, the chi-square test ($df$ = 1, $\chi^2$ = 9.7244, $p$ = 8.184e-3) also confirms a statistically significant relationship at the 5% level between the presence or absence of under-constrained features and CAD models that were created without feedback intervention and those that were created with feedback intervention provided to students. A graphical summary of odds ratios and associated 95% confidence intervals calculated so far is shown in Figure 2.

### *4.3.3 Feedback effects on dormant deficiency*

Analysis of CAD models that contained type I dormant deficiencies (A5) showed that the calculated individual odds yielded an odds ratio $OR$ = 2.636 and a 95% confidence interval $CI$ = [1.376,5.049] with the approximate standard error of the log odds ratio $SE(\ln(OR))$ = 0.3309. This means that the overall odds that a CAD model would contain a type I dormant deficiency were a little above 2.6 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student who had been provided with 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, $\chi^2$ = 8.7453, $p$ = 3.1040e-3), which yields a statistically significant relationship at the 5% level between the presence or absence of type I dormant deficiencies and CAD models that were created without feedback intervention and those that were created with feedback intervention available.

In the case of partially best practice compliant CAD models – all features were fully constrained with OK status – that contained type I dormant deficiencies (A6), the calculated individual odds yielded an odds ratio $OR$ = 2.665 and a 95% confidence interval $CI$ = [1.284,5.530] with the approximate standard error of the log odds ratio $SE(\ln(OR))$ = 0.3726. This means that the overall odds that a best practice compliant CAD model would contain a type I dormant deficiency were again a little above 2.6 times as high for a CAD model that had been created by a student without feedback intervention as for a CAD model that had been created by a student who had been provided with feedback intervention. Again, in this case, the chi-square test ($df$ = 1, $\chi^2$ = 7.0966, $p$ = 7.7213e-3) confirms a statistically significant relationship at the 5% level between the presence or absence of type I dormant deficiencies in best practice compliant CAD models that were created without feedback intervention and those that were created with feedback intervention available. For a graphical summary of all the calculated odds ratios and associated 95% confidence intervals, see again Figure 2.

| *Assessment Criteria* | *Effect* *OR* | *Size* *d* |
|---|---|---|
| Features with Warnings / Failures | 2.719 | 0.553 |
| Un-renamed Features | 2.668 | 0.542 |
| Under-constrained Features | 4.800 | 0.867 |
| Type I Dormant Deficiency | 2.636 | 0.536 |

**Table 1:** Assessment criteria and associated effect sizes.

Using a common conversion method, the effect sizes reported above for dichotomous data based on odds ratios can be transformed into estimates of their counterparts based on Cohen's *d*, which is the number of standard deviations representing a standard effect size measure (cf. [16]). This method is based on the product of the logistic difference and the factor $((3^{1/2})/\pi)$, which yields a standardized mean difference statistic (cf. [15,30,59]). Effect sizes as calculated in this study and their estimated values when transformed into standard effect size measures are shown in Table 1. Those standard effect sizes are not only above the $d = 0.4$ effect size which is regarded as necessary for any educational method or technology to be taken seriously (see also discussions in [32]), but also well-placed within the effect size range argued to be relevant for any feedback intervention (cf. [32,65]).

## 4.4 Discussion

In this study the nature and effectiveness of an educational feedback intervention within an MCAD course for second-year university students has been analyzed. Besides the impact on learning experience and outcomes, the effects on compliance with best practices and on the presence of dormant deficiencies have been of particular interest, as has the extent to which feedback effects and characteristics pertain to task complexity as well as to performance challenges in regard to parametric feature-based CAD model creation.

In reference to research question RQ1 concerning the outcome and performance of students in relation to the quality of the CAD models that were created after the introduction of the feedback intervention, a significant improvement in both CAD model robustness and best practice compliance was observed. This indicates that students indeed used and benefitted from the feedback, as they were able to improve sufficiently to decrease the obvious gap between their former performance and a reference performance. This can be partially attributed to several factors, as follows. Firstly, in the case of CAD model robustness, students were provided with a novel metric linked to the concept of dormant deficiency that allows for a better understanding of, and also insight into, the presence and nature of errors in associativity. This represents a type of feedback on CAD model robustness that no modern commercially available CAD system is yet able to provide (cf.[45]). As the implementation of the feedback agent allows the concept of dormant deficiency to come to life through simulated systematic CAD model alterations and regenerations, students were able to learn from mistakes during interactions with the computerized system in real-time, while analyzing their CAD models under the guidance of the software tool based feedback agent. This suggests that the feedback intervention engages students in effective actions that help improve existing behavior, knowledge, skills, and consequently competency, which is the basic goal of any learning experience. Achieving an understanding of the nature and importance of errors in associativity is quite a difficult task that requires considerable effort from both sides, that is from both the learning and the teaching side. Here, one promising approach is to support self-guided learning through understanding rather than by adding just domain knowledge content (cf. [64]). In this regard the feedback agent provides not only metrics and functionality for detecting actual dormant deficiencies in CAD models, but also information that supports systematic backtracking from their symptoms and effects to the possible root causes of such deficiencies (see also [51]). This, in turn, provides students with opportunities to learn and gain understanding (see also discussions in [2,24,51]) through practical hands-on experience during the analysis and cognitive processing of the detailed interactive feedback that is provided on dormant deficiencies – if such are present in the CAD models. Note that, within this scenario, support is also given to learning about and understanding what not to do, in order to avoid such errors (see also discussions on negative knowledge and expertise in [28,46,49]). Perhaps this might also contribute to a less frequent demand for feedback, and to its being supplied earlier than usual, but with longer lasting effects, as student performance improves and gradually transcends the novice level (see also discussions in [41,52,60].

Secondly, in the case of best practice compliant CAD models, the feedback agent provided a means for support of the conceptualizing and actual measuring of this compliance through explicitly recording and pointing out all the shortcomings and deficiencies in the modeling outcome of a student during interactions with the computerized system in real-time. This detailed, explicit, and point-to-point feedback related to best practices and guidelines also helps to develop a student's awareness of these issues and their contribution to CAD model quality. Although information related to features such as status and name can be provided by most CAD systems, this information is usually dispersed throughout the graphical user interface. Moreover, it is not uncommon that the standard default settings of commercial CAD systems need to be adjusted by the user to make some of this feature-related information visible in the graphical user interface. Hence, to many novices this information remains partly hidden, less visually / cognitively accessible, or overlooked altogether most of the time. Within this scenario, another important factor is the viewpoint from which this information is provided, as it impacts the method and contents of presentation. For example, in the case of an un-renamed feature, a CAD system might just report the generic name of the feature as assigned to it by the system. However, the feedback agent explicitly points out to the student who is interacting with it that this particular feature represents a CAD model shortcoming in regard to best practice compliance, because it remains un-renamed. However, to gain a better insight into the relationships among the feedback, its characteristics, and the way students reacted to it and benefitted from this educational intervention, performance gains and similar factors need to be examined. Consideration must also be given to the impact on skill and competency development, as well as the improvement of awareness in view of CAD model creation-related goals and task complexity. This is carried out in the discussion relating to research question RQ2 that follows next.

As empirical results showed, the feedback intervention across all directions analyzed in the study produced effect sizes that are large enough to be considered not only relevant but strong in the educational field. This demonstrates that the proposed interactive computerized feedback can be regarded as an effective educational intervention that improves student performance through an enhanced learning experience. However, the contributions to enhancing the learning experience, leading to improvements in student performance, were supported in various ways and at different levels of effectiveness by the feedback intervention. In the case of partially best practice compliant CAD models and in regard to un-renamed features (cf. analysis A3), the task complexity both of assigning a name to a feature and of amending an un-renamed feature is low. Locating any un-renamed features – if present – in a CAD model based on the information provided through the system and the feedback agent is also, even for novices, a straightforward process that is not difficult to perform. Therefore, compared to cases of partially best-practice-compliant CAD models where students had to face more complex tasks, the feedback effect was not quite as great as could have been expected. To some extent, this can be attributed to differences in the students' CAD model creation-related goals and to their inconsistent awareness and prioritization of individual best practice compliance criteria. As became evident through student-teacher interactions during CAD course Q&A sessions and CAD laboratory exercises, during CAD model creation, most students focus heavily on the shape of a model rather than on modeling strategy, model robustness, and best practice compliance. Within such a scenario, the assignment and correction of values for parameters that impact the CAD model shape are perceived by students as having a higher priority than the assignment of parameters, which do not have an explicit impact on or functional relationship with the model shape. Here, to raise the feedback effect to the level that should be expected, perhaps it is necessary to improve or even redesign some characteristics of the software tool interface and the manner in which feedback information on un-renamed features is presented and provided.

In the case of partially best practice compliant CAD models regarding features with a warning or failure status (cf. analysis A2), the task complexity of assignment and / or correction of feature parameter values to achieve an OK status can be considered in most cases to be moderate. Since it is more difficult to correctly process and act upon the feedback here, the effect size is a little larger than in the case of best practice compliant CAD models regarding un-renamed features. One contributing factor, partially responsible for this, could be the relationship between feature status and CAD model shape. As discussed earlier, this is an important facet that determines the focus and strength of students' modeling-related goals and their awareness of individual compliance aspects.

In the case of partially best practice compliant CAD models regarding under-constrained features (cf. analysis A4), the task complexity of assignment and / or correction of feature parameter values to achieve fully constrained features is usually within the range of low to medium. This range is usually ensured by the exercise assignments of the CAD course, though some cases could be a little more challenging for novices, depending on the nature and the often unnecessary complexity of feature shapes created by some students. Taking into account the low to medium task complexity the strong impact that constraints have on the feature shape, and the powerful focus on and awareness of the latter, which novices usually exhibit, the large feedback effect size from the study should not come as too much of a surprise. However, as pointed out, task complexity, and thus the way students perform, may vary considerably depending on the unnecessary complexity of individual features and their shapes as created by students – even though that was not required by the exercise. This results in an actual feedback effect that not only is significant but also varies over a wide range. This situation is reflected in the computed statistics, in particular the size, the standard error, and the confidence interval of the feedback effect, which were among the greatest in this study.

In reference to research question RQ2, significant improvements in outcome and in the performance of students in regard to the quality of the CAD models that were created indeed appear to be partially impacted by the extent to which the effects and characteristics of the feedback intervention pertain to the task complexity and the goal settings of CAD model creation and amendment. As the concept of dormant deficiency is novel and was only very recently introduced to the CAD community by the authors (cf. [45,51]), some concrete examples that were encountered during CAD model analysis are provided to enhance transparency and to better illustrate the discussion that follows next. Details of the CAD model that was used for discussing concrete case examples in this paper, together with the embedding in the CAD laboratory exercise and course assignments, can be found in [45]. In the case of CAD model robustness (cf. analysis A5), correctly interpreting the feedback and backtracking from symptoms and effects to the root causes of dormant deficiencies is not always a straightforward process for novices. Therefore, the task complexity can be considered to usually reside in a range from medium to high. However, in many cases, a concrete range cannot be ensured by the exercise assignments of the CAD course due to the nature and complexity of feature associativity itself. This, in turn, partly harks back to the complexity of the feature shapes and feature parameter relationships some students may have created in the first place.

An actual example of a type I dormant deficiency that was detected and verified by human assessors during model analysis is shown in Figure 3. In the example shown in Figure 3(b), the dormant deficiency was activated by a change (value increment) in the radius of the rounded region in the upper front part of the link yoke head. As a result, the extruded cutout feature that was used to create the gap between the yoke ends lost its reference plane. This situation happened because the reference plane used for the cutting profile was unfortunately selected to be vertical and tangential to the round (see again Figure 3(b) and the markings in yellow). However, in such a modeling situation, a different and more adequate geometric constraint should have been used to avoid such a deficiency.

This example is a typical case in which a modeling mistake resulting in an error in feature associativity – that is frequently committed and easily overlooked by novices – creates a dormant deficiency that has no apparent impact on the CAD model (cf. Figure 3(a)) until an alteration takes place. However, the alteration, if activated, suddenly turns into a concrete deficiency following parameter alteration and subsequent model regeneration. Through the software tool-based feedback agent, students can actually see the concept of dormant deficiency coming to life during feedback provision, and they can trace, as well as interact with, all these processes and the CAD modeling environment as they backtrack from deficiency symptoms and effect to root cause (concrete examples are described in [51]).

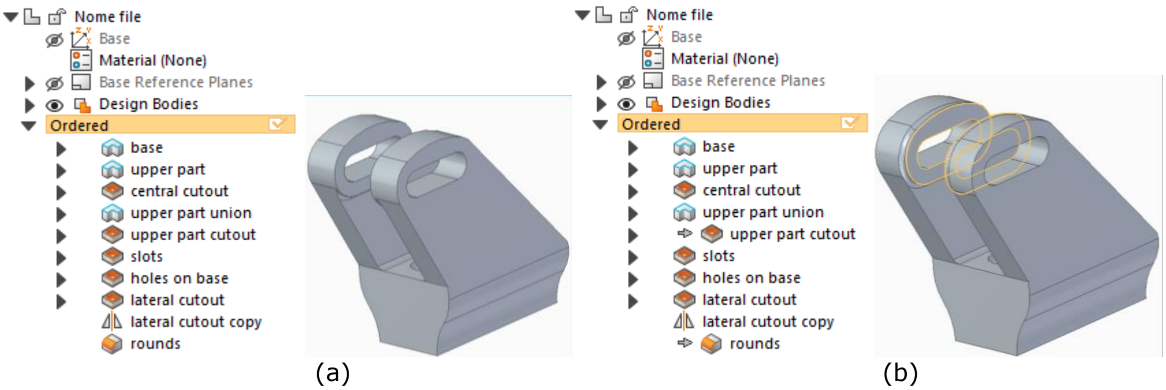


**Figure 3:** Concrete example of a CAD model type I dormant deficiency encountered during CAD model analysis: From left to right: (a) state of the CAD model without any feature failures before the alteration of a critical dimension, (b) actual state of the regenerated CAD model containing failed features and geometric deficiencies after alteration of a critical dimension.

| Changed Feature | Variable | Critical Dimension | Failed Features | |
|---|---|---|---|---|
| upper part | V720 | 26,4 | upper part cutout | rounds |
| upper part | V720 | 21,6 | upper part cutout | rounds |
| upper part | V721 | 21,6 | rounds | |
| upper part | V732 | 22,5 | rounds | |
| upper part union | V1394 | 26,4 | upper part cutout | rounds |
| upper part union | V1394 | 21,6 | upper part cutout | rounds |
| upper part union | V1399 | 26,4 | rounds | |
| upper part union | V1416 | 27,5 | rounds | |

**Figure 4:** Section of a concrete example of the part of the elaborative feedback that provides additional task specific and detailed information on features that failed during model regeneration.

Besides offering a visual representation of CAD model shapes and their geometric/topological properties, the elaborative feedback also provides task-specific and detailed information on the features that failed during model regeneration, along with records on all critical parameters and their values that caused those deficiencies. A snapshot of such task-specific and detailed information relating to the example of the link yoke discussed above (see Figure 3 again) is shown in Figure 4.

Despite the challenges, the provision of the feedback intervention led to a considerable reduction in dormant deficiencies in CAD models and showed effects and confidence intervals that were comparable in size and range to their counterparts in the analysis of best practice compliance. Taking into account task complexity and the difficult nature of the issue, those results were quite encouraging. Contributing factors were the students' strong focus on CAD model shape – geometry/topology is negatively impacted by the presence of dormant deficiencies – and the ability of the feedback agent to bring this concept to life. That is to say that the students could see the impact a dormant deficiency would have on the CAD model shape and could interact with the CAD model and the feedback agent in real-time while trying to discover the root cause of the deficiency and amend the model. In the cases of CAD models in which all features were fully constrained and where there were no warnings or failures (cf. analysis A6), the effect size was a little higher than in other dormant deficiency-related cases. Presumably, this can be attributed to the fact that students who are already able to create partially best-practice-compliant CAD models are also more likely to have better-developed know-how and skills, enabling them to find the root causes of dormant deficiencies and perform adequate corrections.

## 5 CONCLUSIONS AND FUTURE WORK

Results obtained from the first part of this two-part study provide empirical evidence that the feedback intervention introduced in the reconstructed MCAD course was effective in improving the quality of the feature-based CAD models that students were able to produce through CAD laboratory activities and exercise assignments. The encouraging and reassuring outcomes achieved, based on the evaluation of empirical results from the study and compiled as responses to the research questions for the study, were as follows. Through intercommunication processes with the software tool (intervention agent), based on interactive human-computer communication with feedback in real-time, students can self-assess their current performance. That is, students are provided with metrics that can be used to compare the quality of their modeling outcome with that of an expected outcome. In particular, due to the novel concept of dormant deficiency, for the first time students in CAD education have a concrete measure, which is explicitly associated with the robustness of feature-based CAD models. In addition to that, this software tool-based educational intervention allows for the concept literally to come alive, thus giving students real-time experience of what the symptoms and effects of this kind of model deficiency look like in their own created CAD models. This, among other factors, engages students in various cognitive processes and actions, which eventually lead to a successful narrowing of the gap between actual and expected performance. This represents a promising step towards improving the outcomes of student performance in regard to creating feature-based CAD models that are both more robust and in better compliance with best practices. Furthermore, it reduces the gap between initial modeling skills and competency, and projected learning goals, as well as achieving the desired outcomes of learning from errors and benefitting from self-guided formative assessment supported by interactive feedback intervention.

The second part of this two-part study aims to shed some light on, and gain a better understanding of, the student perspective to this feedback intervention and its means of implementation. Therefore, parallel to the introduction of the software tool within the restructured CAD course, a student survey was conducted. Through this questionnaire-based online survey, students were given an opportunity to express their opinions about the newly introduced feedback intervention. That is, they were able to indicate what worked best for them and what did not work well. They were also given the opportunity to mention any shortcomings or omissions in the implementation and to state what kinds of improvements they would like to see in this educational intervention. Analysis and assessment of the data obtained through this survey are currently in progress, with results expected to be published soon.

*Ferruccio Mandorli*, http://orcid.org/0000-0003-4864-5265
*Harald E. Otto*, http://orcid.org/0000-0002-4580-0429

## REFERENCE

[1] Agresti, A. : An Introduction to Categorical Data Analysis, John Wiley & Sons, Hoboken, NJ, USA, 2019.

[2] Ambrose, S. A.; Bridges, M. W.; DiPietro, M.; Lovett, M. C.; Norman, M. K.: How Learning Works: Seven Research-Based Principles for Smart Teaching, Jossey-Bass, San Francisco, CA, USA, 2010.

[3] Attali, Y.; van der Kleij, F.: Effects of feedback elaboration and feedback timing during computer-based practice in mathematics problem solving, Computers and Education, 110, 2017, 154-169. https://doi.org/10.1016/j.compedu.2017.03.012

[4] 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.
[5] Azen, R.; Walker, C. M.: Categorical Data Analysis for the Behavioral and Social Sciences, Routledge, New York, NY, USA, 2021.
[6] Azevedo, R.; Bernard, R. M.: A meta-analysis of the effects in computer-based instruction, Journal of Educational Computing Research, 13(2), 1995, 111-127. https://doi.org/10.2190/9LMD-3U28-3A0G-FTQT
[7] Barana, A.; Marchisio, M.; Sacchet, M.: Interactive feedback for learning mathematics in a digital learning environment, Education Sciences, 11, 2021, 279. https://doi.org/10.3390/educsci11060279
[8] Black, P.; Wiliam, D.: Developing the theory of formative assessment, Educational Assessment, Evaluation and Accountability, 21, 2009, 5-31.
[9] Blair, A.; McGinty, S.: Feedback-dialogues: Exploring the student perspective, Assessment and Evaluation in Higher Education, 38(4), 2013, 466-476.
[10] Borenstein, M.; Hedges, L. V.: Effect Sizes for Meta-Analysis, in: Cooper, H.; Hedges, L. V.; Valentine, J. C. (eds.) The Handbook of Research Synthesis and Meta-Analysis, Russell Sage Foundation, New York, NY, USA, 2019, 207 - 244.
[11] Branch, R. M.: Instructional Design: The ADDIE Approach, Springer, New York, NY, USA, 2009.
[12] 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
[13] Carless, D.: Differing perceptions in the feedback process, Studies in Higher Education, 31(2), 2006, 219-233.
[14] Carless, D.; Salter, D.; Yang, M.; J. Lam, J.: Developing sustainable feedback practices, Studies in Higher Education, 36(4), 2011, 395-407.
[15] Chinn, S.: A simple method for converting an odds ratio to effect size for use in meta-analysis, Statistics in Medicine, 19 (22), 2000, 3127-3131. https://doi.org/10.1002/1097-0258(20001130)19:22<3127::AID-SIM784>3.0.CO;2-M
[16] Cohen, J.: Statistical Power Analysis for the Behavioral Sciences, Erlbaum, Hillsdale, NJ, USA, 1988.
[17] Clariana, R. B.; Ross, S. M.; Morrison, G. R.: The effects of different feedback strategies using computer-administered multiple-choice questions as instruction, Educational Technology Research and Development, 39(2), 1991, 5-17. https://doi.org/10.1007/BF02298149
[18] Cramp, A.: Developing first-year engagement with written feedback, Active Learning in Higher Education, 12(2), 2011, 113–124. https://doi.org/10.1177/1469787411402484
[19] Crisp, B. R.: Is it worth the effort? How feedback influences students' subsequent submission of assessable work, Assessment and Evaluation in Higher Education, 32 (5), 2007, 571-581.
[20] Cutumisu, M.; Schwartz, D. L.: The impact of critical feedback choice on students' revision, performance, learning, and memory, Computers in Human Behavior, 78, 2018, 351-367. https://doi.org/10.1016/j.chb.2017.06.029
[21] Dolors, P. E.; Soledad, M. G.; Pep, S.: The effectiveness of instructor personalized and formative feedback provided by the instructor in an online setting: Some unresolved issues. The Electronic Journal of e-Learning, 14(3), 2016, 196-203.
[22] Dowden, T.; Pittaway, S.; Yost, H.; McCarthy, R.: Students' perceptions of written feedback in teacher education: Ideally feedback is a continuing two-way communication that encourages progress, Assessment and Evaluation in Higher Education, 38 (3), 2013, 349–362.
[23] Ellis, P. D.: The Essential Guide to Effect Sizes: Statistical Power, Meta-Analysis, and the Interpretation of Research Results, Cambridge University Press, Cambridge, UK, 2010.
[24] Fink, D. L.: Creating Significant Learning Experiences, Revised and Updated: An Integrated Approach to Designing College Courses, Jossey-Bass, San Francisco, CA, USA, 2013.

[25] Fleiss, J.; Levin, B.; Cho Paik, M.: Statistical Methods for Rates and Proportions, John Wiley & Sons, Hoboken, NJ, USA, 2003.
[26] 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.
[27] Garrett, J. J.: The Elements of User Experience, Peachpit (Pearson Education Division), Berkeley, CA, USA, 2011.
[28] Gartmeier, M.; Bauer, J.; Gruber, H.; Heid, H.: Negative knowledge: Understanding professional learning, Vocations and Learning, 1(2), 2008, 87-103. https://doi.org/10.1007/s12186-008-9006-1
[29] 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
[30] Hasselblad, V.; Hedges, L. V.: Meta-analysis of screening and diagnostic tests, Psychological Bulletin, 117 (1), 1995, 167-178. https://doi.org/10.1037/0033-2909.117.1.167
[31] Hattie, J; Timberly, H.: The power of feedback, Review of Educational Research, 77 (1), 2007, 81-112. https://doi.org/10.3102/003465430298487
[32] Hattie, J.: Visible Learning: A Synthesis of 800+ Meta-Analyses on Achievement, Routledge, London, UK, 2009.
[33] Hattie, J; Gan, M.: Instruction Based on Feedback, in: Mayer, R. E.; Alexander, P. A. (eds.) Handbook of Research on Learning and Instruction, Routledge, New York, NY, USA, 2011, 249-271.
[34] Haddock, C. K.; Rindskopf, D.; Shadish, W. R.: Using odds ratios as effect sizes for meta-analysis of dichotomous data: A primer on methods and issues, Psychological Methods, 3 (3), 1998, 339-353. https://doi.org/10.1037/1082-989X.3.3.339
[35] 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
[36] Irons, A.: Enhancing Learning through Formative Assessment and Feedback, Routledge, Abingdon, UK, 2008.
[37] Jaakma, K.; Kiviluoma, P.: Auto-assessment tools for mechanical computer aided design education, Heliyon, 5(10), 2019, e02622. https://doi.org/10.1016/j.heliyon.2019.e02622
[38] 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.
[39] Kluger, A. N.; DeNisi, A.: Effects of feedback intervention on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory, Psychological Bulletin, 119(2), 1996, 254-284. https://doi.org/10.1037/0033-2909.119.2.254
[40] Kornell, N.; Hays, M. J.; Bjork, R. A.: Unsuccessful retrieval attempts enhance subsequent learning, Journal of Experimental Psychology: Learning Memory and Cognition, 35(4), 989-998, 2009. https://doi.org/10.1037/a0015729
[41] Leibold, N.; Schwarz, L. M.: The art of giving online feedback, Journal of Effective Teaching, 15(1), 2015, 34-46.
[42] Maier, U.; Klotz, C.: Personalized feedback in digital learning environments: Classification framework and literature review, Computer and Education: Artificial Intelligence, 3, 2022. https://doi.org/10.1016/j.caeai.2022.100080
[43] Mandorli, F.; Otto, H. E.: Systematic support of learning from errors and negative knowledge development in MCAD education: Empirical analysis of student feedback, Computer-Aided Design and Applications, 17(2), 2020, 384-406. https://doi.org/10.14733/cadaps.2020.384-406

[44] Mandorli, F.; Otto, H. E.: A Systematic Approach to Innovative MCAD Education Based on Negative Knowledge Development and Formative Feedback, in: Rizzi, C.; Campana, F.; Bici, M.; Gherardini, F.; Ingrassia, T.; Cicconi, P. (eds.) Lecture Notes in Mechanical Engineering (Design Tools and Methods in Industrial Engineering II), Springer, Cham, Switzerland, 2021, 839-850. https://doi.org/10.1007/978-3-030-91234-5_85
[45] Mandorli, F.; Otto, H. E.: Improving the learning experience within MCAD education: A tool for students to assist in self-assessment during modeling exercises, Computer-Aided Design and Applications, 19(3), 2022, 534-560. https://doi.org/10.14733/cadaps.2022.534-560
[46] Minsky, M.: Negative expertise, International Journal of Expert Systems, 7(1), 1994, 13-19.
[47] Mulliner, E.; Tucker, M.: Feedback on feedback practice: Perceptions of students and academics, Assessment and Evaluation in Higher Education, 42(2), 2015, 266-288. https://doi.org/10.1080/02602938.2015.1103365
[48] Nicol, D.; Thompson, A.; Breslin, C.: Rethinking feedback practices in higher education: A peer review perspective, Assessment and Evaluation in Higher Education, 39(1), 2014, 102-122.
[49] Otto, H. E.; Mandorli, F.: Integration of negative knowledge into MCAD education to support competency development for product design, Computer-Aided Design and Applications, 14(3), 2017, 269-283. https://doi.org/10.1080/16864360.2016.1240448
[50] Otto, H. E.; Mandorli, F.: A framework for negative knowledge to support hybrid geometric modeling education for product engineering, Journal of Computational Design and Engineering, 5, 2018, 80-93. https://doi.org/10.1016/j.jcde.2017.11.006
[51] Otto, H. E.; Mandorli, F.: Dormant deficiency: A novel concept to direct cause-effect CAD analysis, Research in Engineering Design, to appear.
[52] Park, J.-A.; Johnson, D. A.; Moon, K.; Lee, J.: The interaction effects of frequency and specificity of feedback on work performance, Journal of Organizational Behavior Management, 39(3-4), 2019, 164-178. https://doi.org/10.1080/01608061.2019.1632242
[53] Polanin, J. R.; Snilstveit, B.: Campbell Methods Policy Note on Converting Between Effect Sizes, The Campbell Collaboration, Oslo, Norway, 2016. https://doi.org/10.4073/cmpn.2016.3
[54] Price, M.; Handley, K.; Millar, J.: Feedback: Focusing attention on engagement, Studies in Higher Education, 36(8), 2011, 879-896.
[55] Proske, A.; Körndle, H.; Narciss, S.: Interactive Learning Tasks, in: Seel, N. M. (ed.) Encyclopedia of the Sciences of Learning, Springer, New York, NY, USA, 2012, 1606-1610.
[56] Poulos, A.; Mahony, M. J.: Effectiveness of feedback: The students' perspective, Assessment and Evaluation in Higher Education, 33, 2008, 143-154.
[57] Sadler, D. R.: Formative assessment and the design of instructional systems, Instructional Science, 18, 1989, 119–144.
[58] Sadler, D. R.: Beyond feedback: Developing student capability in complex appraisal, Assessment and Evaluation in Higher Education, 35(5), 2010, 535-50.
[59] Sánchez-Meca, J.; Marín-Martínez, F.; Chacón-Moscoso, S.: Effect-size indices for dichotomized outcomes in meta-analysis, Psychological Methods, 8(4), 2003, 448–467. https://doi.org/10.1037/1082-989X.8.4.448
[60] Schwerter, J.; Wortha, F.; Gerjets, P.: E-learning with multiple-try-feedback: Can hints foster student's achievement during the semester, Educational Technology Research and Development, 70, 2022, 713-736. https://doi.org/10.1007/s11423-022-10105-z
[61] Shute, V. J.: Focus on formative feedback, Review of Educational Research, 78(1), 2008, 153-189. https://doi.org/10.3102/0034654307313795
[62] Smithson, M.: Confidence Intervals, Sage Publications, Thousand Oaks, CA, USA, 2003.
[63] Van der Kleij, F. M.; Feskens, R. C. W.; Eggen, T. J. H. M.: Effects of feedback in a computer-based learning environment on student's learning outcomes: A Meta-analysis, Review of Educational Research, 85 (4), 2015, 475-511. https://doi.org/10.3102/0034654314564881
[64] Wiggins, G.; McTighe, J.: Understanding by Design, Association for Supervision and Curriculum Development, Alexandria, VA, USA, 2005.

[65] Wisniewski, B.; Zierer, K.; Hattie, J.: The power of feedback revisited: A meta-analysis of educational feedback research, Frontiers in Psychology, 10, 2020, 3087. https://doi.org/10.3389/fpsyg.2019.03087