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Systematic Support of Learning from Errors and Negative Knowledge Development in MCAD Education: Empirical Analysis of Student Feedback

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Abstract. To address some of the shortcomings of the traditional approach to CAD education in relation to the increasingly complex and highly competitive global labor markets, while also taking advantage of recent developments in educational research and cognitive science related to how students learn, a novel approach to improving CAD education has been developed and implemented. The approach integrates negative knowledge and learning from errors as crucial elements in combination with traditional teaching methods (positive knowledge) and formative assessment/feedback. To examine different facets of teaching/learning-related phenomena aimed at providing grounds for improving learning outcomes achieved within a recently restructured MCAD course, empirical research was conducted. In this paper, the results of that empirical research are presented and discussed in regard to learning experience and self-evaluated competency development. The results and insight gained herein are based on student feedback from a set of over 700 questionnaires collected and analyzed using a multi-method approach.

Keywords: competency development, integrated teaching method, negative expertise, strategic knowledge build-up, learning experience, curriculum design.
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1 INTRODUCTION

In various commercial and industrial engineering settings CAD systems are increasingly being used on a broad base. In particular, the spread of mechanical computer-aided design (MCAD) systems within the mechanical engineering industry has increased in a remarkable way regarding both the depth of application range and the level of technological development. The technological improvements, in particular, have led to considerable complexity in the models managed by modern MCAD systems, and an increase in the requirements related to keeping models consistent and usable throughout all the different phases of the modeling process. This, in turn, puts higher demands on know-how and competency on the user side. It is essential to adopt appropriate design and modeling strategies, and these are becoming an indispensable prerequisite for the efficient and effective operation of modern MCAD systems, despite widespread efforts to develop user-friendly modeling environments. Lately, drastic changes in product development and the ever-increasing adoption of MCAD technology in industry have, amongst other causes, led to a fresh and noticeable increase in interest in MCAD education.

In most institutions of higher education, the traditional approach to CAD education is based on the teaching of system commands, the interaction with user interfaces, domain subject tutorials, and best practices, with the overall aim of developing sufficient domain knowledge, know-how, and skills to operate a modern CAD system. However, learning outcomes achieved with this educational approach fall short in several respects regarding the current expectations of the labor market from graduates of institutions of higher education. From an educational point of view, the issues related to developing know-how and skills actually pertaining to elements of professional CAD competency represent a new challenge, as they require innovative teaching methodologies capable of supporting the development of strategic know-how and basic domain expertise, which are beyond what is currently achieved with the traditional approach to CAD education. One of the major drawbacks of the traditional teaching approach is that when students have to face new modeling situations, not explicitly encountered during training, due to their being novices, they usually do not recognize that certain strategies may lead to design and modeling situations best avoided. This is because tutorials and best practices usually teach only "*what to do*" (positive knowledge), though in many situations being aware of critical circumstances that might lead to mistakes and errors, and thus also knowing "*what not to do*" (negative knowledge) is equally important for achieving a desired outcome.

To overcome some of the current shortcomings outlined above, the authors have devised and implemented a novel educational framework, aimed at integrating the development of positive knowledge with the development of negative knowledge and doing this from both sides, namely both teaching and learning [35]. The design of this novel framework was motivated by, among other things, work on negative expertise and workplace-related learning and error handling, with a particular emphasis on issues related to negative knowledge and learning from errors. This is of particular importance within the context of competency development as, according to current research (cf. [19,34]), it can contribute to fostering certainty about domain knowledge and related actions when solving a problem. It also directly influences performance by allowing for the identification and correction of inadequate methods of proceeding, thus increasing the efficiency of problem solving, while additionally promoting the quality and depth of reflection on actions.

2 SCOPE AND OBJECTIVES

The newly developed educational framework is now in its third year of successful operation within the department where the authors operate. Therefore, various forms of student feedback embodied in observational records, CAD models, final exam material submissions, and questionnaires have been obtained and systematically filed for the purposes of post-processing and analysis. Before going into further detail, perhaps we might offer a brief chronology with reference to material published earlier by the authors related to this project on innovation in CAD education and corresponding to the restructuring of the MCAD course. This will better position the research reported in this paper.

First, in 2013, work was presented in [30] related to the definition of an architecture and framework for a newly developed approach based on model evaluation concepts related to negative knowledge and domain knowledge which could be directly translated into practice. In particular, newly developed concepts such as action constraints, critical situations, and CAD model deficiencies, considered central to the framework, were presented. Research and innovation efforts were aimed at improving learning experiences and learning outcomes with an emphasis on skill acquisition and competency development for CAD education in mechanical engineering. At that time, solid modeling in general was accentuated within the teaching and learning context.

Second, in 2017, the first results were presented in [35] on how the novel approach based on the newly developed framework had been translated into practice through implementations resulting in a completely restructured MCAD course. Due to some changes in the setting of learning outcomes over time, surface-based modeling was now accentuated within the teaching and learning context. This required, among other changes, a review and modification of CAD model deficiencies as developed, and also definition of new types. The latter was necessary to facilitate the capturing and handling of newly introduced critical situation entities, arising due to the surface-based modeling context. Note, however, that the architecture and framework of the novel approach, as originally proposed, have remained basically unchanged.

Third, in 2018, results of the implementation experience of, and first learning outcomes achieved within, the reconstructed MCAD course were reported in [31]. Here the focus within the evaluation of learning outcomes was mostly oriented towards an educator's viewpoint. Additional modifications within the teaching and learning context, found to be necessary to better adapt to the wider MCAD course requirements (see also discussions in [5]), resulted in our finally settling for hybrid modeling as the target geometric modeling domain. This required, among other changes, increased emphasis on the previously introduced concept of a *usable model* within both lectures and exercises. It also became necessary to consider the know-how and skills required within CAD competency to create such usable models. These became the basic elements of the learning outcomes as stipulated for the MCAD course in its current form.

To inform and thus support efforts to improve both the learning experience and the learning outcomes, a better understanding is necessary of how students perceive their learning environment and their own learning-related goal settings, efforts, and engagement (cf. [15,20,38]). However, approaches such as classroom and exercise observations and tests of subject matter are intrinsically limited, and cannot provide a complete picture of the preferences, values, and amount of investment students place on their learning environment and learning activities (see also discussions in [9,12,29]). Therefore, the research reported in this paper is focused on determining what learning experiences and outcomes were achieved with the restructured MCAD course from the viewpoint of students. Specific objectives within individual empirical study designs were aimed at shedding some light on which teaching/learning methods students preferred and valued most, the reasons and specific notions that provided grounds for their preferences and opinions, and finally how students' self-evaluated performance and confidence compared to the actual performance and results they achieved in tests. Note that the academic year 2013/14 was the last time the course was conducted in its previous form. In the academic year 2014/15, implementation of the newly developed course structure started. In the academic year 2015/16, basic restructuring of the course was completed. Therefore, the empirical study reported in this paper is based on student feedback from the past three academic years from 2015/16 to 2017/18.

3 BACKGROUND AND RELATED WORK

To address some of the shortcomings of the traditional approach to CAD education in relation to the increasingly complex and highly competitive global labor markets (cf. [8,11,16]), while also taking advantage of recent developments in educational research and cognitive science related to how students learn (see also discussions in [1,14,18,28,32,45,46,47]), a novel approach to improving CAD education has been developed and implemented as follows. The approach integrates negative knowledge and learning from errors as crucial elements (cf. [19,22,33,36]), in combination with traditional teaching methods (positive knowledge) and methods of formative assessment (cf. [4,27,40]) and formative feedback (cf. [6,23,41]), as shown in Fig.1. Here development of positive knowledge is usually based on lectures on domain specific factual knowledge, which is supported by conventional education material oriented on tutorials and best practices. Negative knowledge and its inculcation/build-up are formulated as an element of strategic knowledge development aimed at promoting awareness of and constraining actions within critical modeling situations that would otherwise lead to errors and mistakes. Notice that some elements of the concept of negative knowledge have been mapped to the concept of geometric model deficiency. This concept is used to form normative knowledge as a qualitative measure to help express certain characteristics of situations during modeling.

Such characteristics usually lead to models being poorly structured and are thus best avoided. To implement the approach and integrate it into the current CAD course, various modeling exercises are provided, in addition to the traditional lectures and tutorials, and these exercises are individually designed for different learning aspects. At this point it should be explained that, during the first series of exercises, students are motivated and guided to develop their own CAD models on the basis of guidelines outlined during tutorials. This is consistent with the predominantly tutorial-based teaching used at the beginning of the course, with lectures initially emphasizing the development of positive knowledge and competency. In the second series of exercises, students are requested to use their own previously created CAD models for further practice in subsequent CAD laboratory assignments. In the second part of the course, where learning from errors is increasingly encouraged in classes, the exercises have been designed to provide ample chances for encounters and confrontations with CAD model deficiencies.

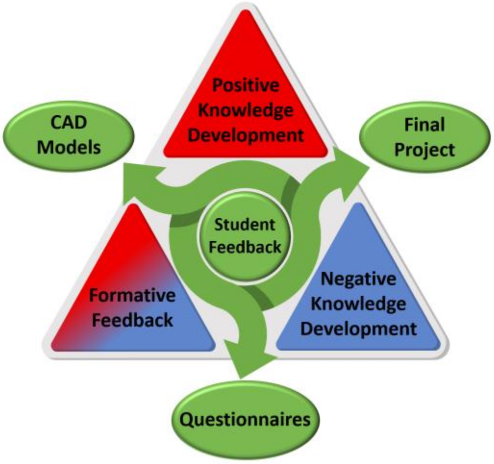

Figure 1: Overview of structural components related to knowledge development and feedback within the newly developed integrated MCAD course.

This policy is aimed at supporting the development of analytic and strategic CAD modeling skills and of situation awareness and domain knowledge about what not to do, in order to avoid mistakes. If CAD model deficiencies are encountered, which is most likely as novices are usually not able to create CAD models without deficiencies during the first series of exercises, students will confront them under guidance and with the support of an academic supervisor, and the situations and factors that have led to those deficiencies are systematically analyzed using situation boxes, action constraints, etc. (cf. [35]). This will help the students to gain an understanding of their errors and learn how to devise strategies to recover from mistakes committed earlier and ameliorate the situation if possible. Some examples of errors and mistakes actually encountered during exercises and deemed most significant and useful for learning are then discussed later in classes. Within loops of formative assessment/feedback that are coordinated with elements of positive/negative knowledge development and learning from errors, results of additional exercise homework and unsupervised CAD laboratory assignments are collected and assessed, to identify shortcomings and errors, which usually remain hidden from students due to their limited domain knowledge and expertise. During lectures, and also online through the CAD course web site, representative examples of the assessed exercises are also used later to discuss issues relating to critical modeling situations and model deficiencies, and how to prevent them. More details on the theoretical foundation and the implementation of the teaching approach can be found in [30,31,35].

4 EMPIRICAL STUDY

4.1 Method and Study Context

Empirical work related to the design and implementation of survey and test material, data collection, and analysis has been conducted within a multi-method research study [43], which consists of both quantitative and qualitative data and analysis components. The study was aimed at examining different facets of teaching/learning-related phenomena and at improving description of and insight into the relationship between the newly developed and implemented approach and its contribution to enhancing MCAD education. A web site has been developed for the distribution and collection of exercise material and the implementation and administration of a set of online questionnaires. These have been designed as a course survey, a self-report, and a test on CAD domain subject knowledge. This web site is contained within the e-learning platform of the institution's engineering faculty using *Moodle*, an open source learning management system (cf. LMS in [44]). Online participation in the questionnaires by students is both anonymous and voluntary. Data collection through the online questionnaires has been carried out over the past three consecutive academic years from 2015/16 to 2017/18, involving three different student cohorts. Each student cohort has consisted of about 140 to 160 students. The response rate, averaged across all sets of questionnaires, was between 66.8% and 79.3%. As described by registrar statistics, students enrolled in the MCAD course were mechanical engineering sophomores, of whom about 20% had some experience as beginners using a commercial computer-aided design and drafting system, namely AutoCAD developed by Autodesk, mostly for learning computer-aided 2D drafting and drawing. This fact reflects the secondary educational background of the students enrolled in the course, as only about 5% were from traditional liberal arts high schools, while about 65% were from science high schools and about 30% were from various other types of secondary schools, mostly technical. Female students made up, on average, 10% of the classroom population.

Assessment of performance and learning outcome was carried out based on observation records during laboratory exercises and results of questionnaires, with the latter being structured into surveys and domain-subject-related tests. One component within the set of two questionnaires was a form of self-report. One questionnaire was administered before and the other after the introduction of negative knowledge into the current MCAD course. Thus these questionnaires served both as a correlational study and as surveys. One part of the study was aimed at self-assessment regarding elements of competency considered as psychological constructs, such as confidence and a subjective rating of personal development of subject-related skills and knowledge. As a measurement instrument for analyzing variations in response that correlate with relevant outcome variables, ordered response rating scales were employed. Another part of the survey, which employed both single-choice and open-ended questions, was aimed at a better understanding of how components used for the teaching of positive knowledge and negative knowledge were perceived by students and how the data on student opinions related to dimensions of negative expertise. The individual parts of the multi-method study pertaining to the different facets of teaching/learning-related phenomena, as briefly outlined above, are described in the following sub-sections.

4.2 Personal Preferences Regarding Teaching/Learning Methods

4.2.1 Specific objective and study design

This first part of the multi-method study was aimed at providing insight based on student surveys on how the teaching/learning methods used for the development of positive and negative knowledge and competencies were perceived by students in the restructured MCAD course. The surveys, which were administered as a part of a set of online questionnaires, were designed to obtain feedback on students' opinions and preferences for the teaching/learning methods that they encountered during their studying and learning experience within the restructured MCAD course. In particular, participants were asked to state their preference for a teaching/learning method based on usefulness and importance. The survey provided five options for stating a preference. Three options related to an integrated teaching/learning method with an emphasis on either tutorial-based teaching or learning by error, or no emphasis considering both tutorial-based teaching and learning by error to be equally important and useful components. The other two options related to a non-integrated single method represented by either tutorial-based teaching or learning by error. In order to additionally provide the choice of not answering the survey, which was part of a set of questionnaires, while supporting data integrity, subjects were also allowed to explicitly respond that they were unable to answer. Participants were also asked to rate their attendance at classes, for both lectures and exercises, as "all", "almost all", "about half", "few", or "none". No time limit was imposed on answering the questionnaires, as they were administered as a part of the voluntary anonymous online survey that was outlined earlier. Once the questionnaires had been submitted, participants were not able to review or change their answers. Note that this first part of the study is divided into two segments related to the type of survey data used for the analysis.

4.2.2 Results and discussion

From the surveys regarding students' preferences for, and opinions about, teaching and learning methods used in the restructured MCAD course, which were administered within the final questionnaires covering the past three academic years, 313 completed responses have been collected. Of the 313 responses, 302 were used in the first segment of this first part of the study. The number of responses related to teaching/learning method preferences for each academic year is as follows. 115 responses were from 2015/16, 101 responses were from 2016/17, and 97 responses were from 2017/18. Of the 313 responses, 302 were linked to a valid answer in respect to a teaching/learning method preference, while 11 responses, 6 from 2016/17 and 5 from 2017/18, stated that the subject was unable to answer. A graphical summary in the form of a stacked bar chart [24] of these data related to the students' preferences for particular teaching/learning methods is given in Fig.2.

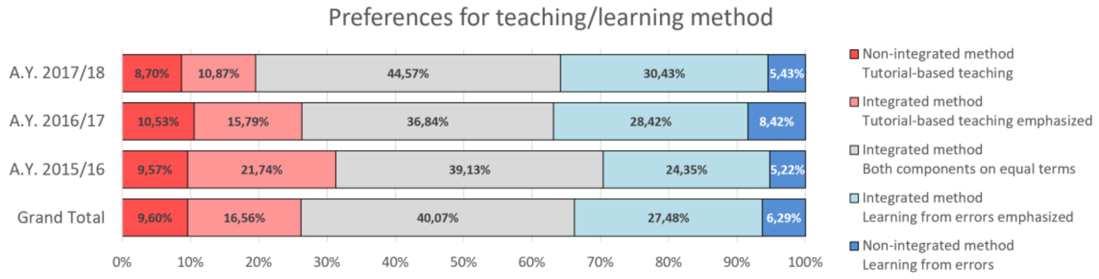

Figure 2: Graphical representation of proportions of preferences for teaching/learning methods.

Of the 302 responses, 84.11% showed a preference for an integrated teaching/learning method that combines a tutorial-based teaching approach with learning from errors. Only a relatively small proportion of 15.89% showed a preference for a non-integrated method. Within the responses expressing a preference for an integrated teaching/learning method, 40.07% considered both the tutorial-based teaching and the learning from errors equally important and useful, and thus considered them as components that should be equally balanced and focused on in the course. 27.48% indicated that within a preference for an integrated method, learning from errors was more important and useful than the component related to tutorial-based teaching, and hence efforts within the course related to teaching and learning should be more focused on and balanced towards the development of negative knowledge and expertise, which is explicitly promoted by learning from errors. Responses indicating the opposite position, that is considering tutorial-based teaching to be the more important and useful component within the preference for an integrated method, were found in 16.56% of the final surveys. Responses indicating a preference for a non-integrated method were found to being sub-divided into preferences for tutorial-based teaching at 9.60% and learning from errors at 6.29%. Due to the considerable differences in the characteristics of tutorial-based teaching and learning from errors used to address the development of positive and negative knowledge, as well as competency, within an integrated approach, the results outlined above also need to be evaluated in respect to the rate of course attendance. This step is described in detail in the next segment of this part of the study.

For the second segment of this first part of the study, additional data on self-rated course attendance obtained through the surveys administered within the final questionnaires, as described elsewhere in this paper, were employed and correlated to the above survey data. This permitted an empirical evaluation to be made based on bivariate analysis of cross-sectional data regarding possible relationships between the preference of teaching/learning method and course attendance. Course attendance rates were sub-divided into five groups, those who attended all, almost all, about half, a few, or no lessons and exercises. The survey data revealed that 50.80% of students attended all or almost all classes of the course, while 49.20% of students skipped half or more of the lessons and exercises. More specifically, 15.97% had attended all lessons and 34.82% had attended almost all lessons. 25.24% had attended about half of the lessons, 17.57% had attended only a few lessons and 6.39%, had not attended at all. A graphical summary of these data regarding self-rated course attendance is shown in Fig.3. The data suggested that the overall pattern of attendance at classes had been quite stable over the three academic years. Although remaining below the 10% level, there was some noticeable difference (proportion factor 2.3) in the proportion of students who attended no class at all over the last two academic years.

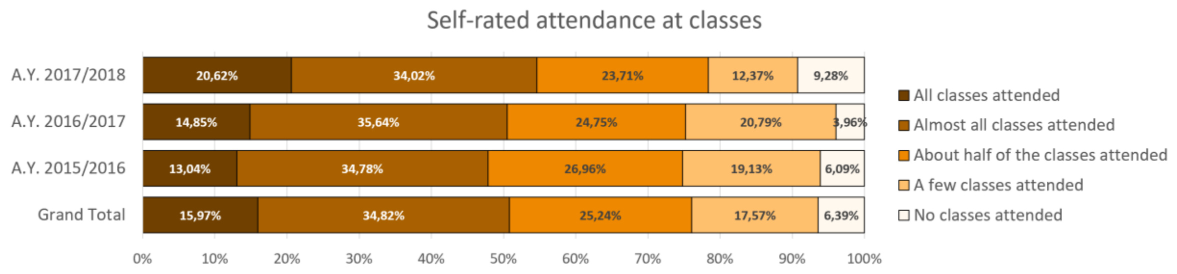

Figure 3: Graphical representation of proportions of self-rated attendance at classes.

Now, starting from the data as shown in Table 1, statistical analysis based on cross-classified frequencies of method preferences and attendance at classes can be performed at two levels, namely at the method level of integrated methods (R1 to R3) and non-integrated methods (R4 and R5), crossed with low attendance (C1 to C3) and high attendance (C4 and C5), and at the component level, i.e. tutorial-based teaching (R3 and R4) and learning from errors (R2 and R5). The first analysis scenario yielded a statistically significant relationship that was detected between the preference for type (integrated/non-integrated) of teaching/learning method and attendance at classes (Pearson's test of independence for $df = 1$, $\chi^2 = 6.278$, $p = 1.223e\text{-}2$). As this statistic provides evidence of a relationship at the 0.05% level of significance with a magnitude of chi squared exceeding 3.841 considering $df = 1$, further analysis into the nature of this relationship is warranted. The second analysis scenario did not yield a statistically significant relationship at the

0.05% level between the preference for tutorial-based teaching and learning from errors, and attendance at classes (Pearson's test of independence for df = 1, χ^2 = 3.693, p = 5.464e-2). However, very narrowly missing statistical significance at the 0.05% level should not impede further analysis into factors that are related to attendance at classes, tutorial-based teaching, and learning from errors, as these are important from an educational viewpoint in the study presented. Therefore, further detailed analysis in this direction was taken up as reported in several sub-sections elsewhere in this paper.

To determine further characteristics of the statistical analysis scenarios just discussed, a measure of the statistical significance of association, such as a magnitude and strength/degree of association between the variables of the two data sets and an estimate for the relationship with confidence interval based on probability was used. However, in addition, a measure in the form of a contingency table based cross-product ratio, in the literature commonly referred to as an *odds ratio* [42], was chosen (see also discussions on the odds ratio and the related rate ratio measure, the *relative risk*, originally developed by J. Cornfield as reported in [17]). Calculation of the ratio of probability for students with a high course attendance rate, that is those having attended all or almost all lessons and exercises of the course, who also had a preference for the integrated teaching/learning method yielded an odds value of 8.24. This indicates that, for every student in this course attendance rate group who was found to have a preference for a non-integrated method, about eight students were found to have a preference for an integrated method. In the case of students with a lower attendance rate, that is those having skipped half or more of the course, who showed a preference for the integrated teaching/learning method, the odds value was only 3.68. Therefore, the odds ratio computes to OR = 2.239. Employing the formulae given in [2,17], a standard error denoted by SE for the (natural) logarithmic odds ratio, here referred to as the *log odds ratio* and computed as ln(OR) = 0.806, can be used to obtain a 95% confidence interval for the odds ratio itself and denoted by CI, which was computed as CI = [1.180, 4.252]. Note that due to the asymmetrical nature of the odds ratio scale, the odds ratio, 2.239, is not actually in the center of the confidence interval CI. Thus, according to those calculations, the overall odds that students have a preference for the integrated teaching/learning method is almost 2.5 times as high for students who have attended all or almost all of the course as for students who have skipped half or more of the course. At this point, a careful reading of the data suggests that a certain amount of attendance at classes is necessary for students to develop a critical mass of interest and learning task engagement (cf. [7,9,25]), to actually comprehend both the nature and workings of the integrated teaching/learning methods as provided in the restructured MCAD course and their impact on competency development. In the case of negative knowledge, and expertise development and learning from errors, this issue is of crucial importance. However, it is difficult to grasp this a priori, especially from the student perspective, because most primary and secondary education is based on positive knowledge development, positive ideal exercise examples, and teaching methods focusing on avoiding errors and mistakes during training, even considering them as failures. Hence, students are not used to learning from errors, and they may not even consider that learning from errors in a systematic manner is an element of competency development. Students who engage more on a surface approach to learning, in contrast to their peers with a deep approach to learning (see again [15]), are usually differently motivated (see also [26,37]) and less emotionally and cognitively engaged with learning tasks, and thus their ability to correctly and fully perceive the overall potential of their learning environment, and also their own potential, is limited.

Further analysis of data obtained from teaching/learning method preference responses in relation to self-rated course attendance (cf. Table 1) yielded some additional insight, outlined as follows. Students with a high attendance rate who attended all or almost all lessons also showed a high rate in their preferences for an integrated teaching/learning method, with particularly high rates (42.59%, 46.94%) in the case of a method where both components, tutorial-based teaching and learning from errors, were assumed to be equally useful and important. However, there was a considerable difference between students who attended all lessons and those who attended almost all lessons regarding their preferences for an integrated method where learning from errors is emphasized (38.78%, 6.12%) and an integrated method where tutorial-based teaching is emphasized (27.8%, 17.59%). This translates into preference rates for learning from errors being between about 1.5 and 6.5 times as high as those for tutorial-based teaching within integrated method preferences.

		Attendance at classes				
		C1 None	C2 A Few	C3 About half	C4 Almost all	C5 All
R1	Integrated method Both components on equal terms	42.11	31.25	37.18	42.59	46.94
R2	Integrated method Learning from errors emphasized	15.79	27.08	23.08	27.78	38.78
R3	Integrated method Tutorial-based teaching emphasized	10.53	16.67	23.08	17.59	6.12
R4	Non-integrated method Tutorial-based teaching	21.05	16.67	8.97	8.33	2.04
R5	Non-integrated method Learning from errors	10.53	8.33	7.69	3.70	6.12

Table 1: Proportions of teaching/learning method preference responses in relation to the amount of course lessons attended.

Students in this attendance group reached levels of learning task engagement and interaction with learning and exercise material, related to, among other factors, being on task, exerting effort, and being invested in tasks (cf. [7,10]) that helped to further not only motivation (see also work on students' perception of relatedness, autonomy, and competency regarding intrinsic motivation and learning tasks as reported in [21]), but also the capacity to more correctly reflect on their own learning process and its progress and thus which teaching/learning methods fitted their needs best. Students in this attendance group also seemed to understand the particular benefits and workings of each teaching/learning method up to the level possible for undergraduate students. This was also reflected in the open-ended answers they gave in the opinion poll (details are presented in the second part of this study). Most importantly, students here understood that in order to learn from error work and actually put themselves into a position to contribute their fair share in translating the potential of negative knowledge and competency development into successful learning outcomes, they needed to attend classes, actively participate in class discussions and laboratory exercises, and make as much use as possible of homework assignments and formative feedback.

Students with attendance of about half also showed a strong preference for an integrated teaching/learning method. However, here preferences for integrated methods emphasizing either tutorial-based teaching or learning from errors were at equal levels (23.08%), well below the preference rate for an integrated method where both components were considered equally useful and important (37.18%). Preference rates for tutorial-based teaching appeared to be slightly higher than those for learning from errors, though both stayed well below the two-digit value range of the rates for integrated methods. The teaching/learning method preference pattern for students in this attendance group was similar to that of their peers in groups with higher class attendance in respect to a predilection for integrated teaching/learning methods. This included both integrated methods where both components were considered to be equal and those that had an emphasis on either tutorial-based teaching or learning from errors. This indicates that students understood the value and general importance an integrated approach to teaching and learning had for their own development and academic advancement. However, there still seemed to be a lack of clear understanding as to what the actual benefits and particular contributions of the individual teaching/learning method components were. In particular, the benefits and workings of learning from errors seemed to be less understood than their counterparts in the case of tutorial-based teaching. There was also a relatively strong penchant for non-integrated teaching/learning methods among students in this attendance group. These observations were echoed not only by the teaching/learning method preference pattern, but also by the type of category and the quantity of arguments and opinions that were provided by the students in this attendance group (details are given in the second part of this study).

Students who had attended only a few lessons showed higher preference rates for non-integrated methods than their peers in the high attendance group. In particular, preferences for tutorial-based teaching went up to 16.67%, while preferences for non-integrated methods were only 8.97% for students who had attended at least half of the lessons. Preferences for learning from errors (8.33%) in this low attendance group were also found to be higher than in groups where students had attended at least half of the lessons (7.69%). The teaching/learning method preference pattern for students in this attendance group was quite different from that in groups with medium or high/very high class attendance. It appeared that students in this low attendance group had much lower learning task engagement than their peers in the higher attendance groups, most probably in each of the dimensions, that is affective, cognitive, and behavioral (see again [7,10]). As they had missed most of the lessons and exercises, they had not been able to benefit from class discussions and formative feedback. They had also been deprived of active participation and engagement in tasks related to learning from errors. Note that in order to execute, as well as achieve, learning from errors, crucial elements are necessary. These include competent academic supervision, guidance, and systematic support for meaningful reflection and a posteriori constructive analysis, but also required are an educational environment and controlled situations where it is safe to commit errors and mistakes for the sake of learning and development. Although students in this low attendance group can access some teaching/learning material online, it is mostly related to tutorial-based domain subject education, which is a part of positive knowledge and skill development. These students are almost completely excluded from the teaching/learning cycle dedicated to negative knowledge and competency development. These unfortunate circumstances leave students in this low attendance group without any experience in or genuine understanding of systematically learning from errors and its central role not only within negative knowledge and competency development, but also in the wider context of an integrated teaching/learning approach. Here the former, being a prevalent legacy from secondary education, is difficult to overcome in higher education, where, in most cases, overall campus and teaching environments are still not sufficiently structured towards motivating and empowering students to better approach and direct their own learning tasks and processes.

Students who had not attended any lessons showed the lowest preference rate of any group for the integrated teaching/learning method with an emphasis on learning from errors (15.79%). However, in case of preferences for non-integrated methods, their ratings were found to be higher and in the same order as the ratings of their peers in the low attendance group. In particular, preferences for tutorial-based teaching and learning from errors were 21.05% and 10.53%, respectively. This preference rate for tutorial-based teaching was the second highest preference rate within this attendance group, and also the highest rate within any group for this teaching method. What was unexpected and quite surprising was that this attendance group also provided the highest rate within any group for learning from errors. In fact, as may be surmised from the data and observations reported so far, the teaching/learning method preference pattern for students in this attendance group was not similar to that of any other class attendance group. Even the detected predilection for integrated teaching/learning methods, where components of both methods were considered to be equally important and useful, which was observed across other class attendance groups, was missing in this group, and, in general, preferences for non-integrated teaching/learning methods dominated. Also, the results of the opinion poll indicated that students in this attendance group had quite a limited understanding about the nature and workings of learning from errors. There is obviously considerable room here for improving motivation and all dimensions regarding engagement in learning tasks.

These measure outcomes and quantitative results provide further empirical evidence for a positive relationship between attendance at courses and students' preferences for integrated teaching/learning methods. This leads to an increase in grasping the value of methods enabling and supporting development of negative knowledge and competency, which in turn also relates to the development of strategic knowledge and skills. In particular, it is indicative of a trend in which an increase in attendance at classes, both lectures and exercises, results in a more active interaction with study material. This leads to a different learning experience and consequently a differently developed competency and skill level. It also fosters a better understanding and appreciation of integrated teaching/learning methods, as implemented in this restructured MCAD course, eventually expressed as an increase in related preference rates.

4.3 Grounds for Personal Teaching/Learning Method Preferences

4.3.1 Specific objective and study design

Research exploring complex phenomena of individuals' life worlds, while seeking insight that sheds light on their possible causes and reasons, usually requires, besides evaluation of quantitative data, also a qualitative analysis of narrative data given in visual or textual form. In this second part of the multi-method study, narrative data was obtained through written comments within open-ended questions asking subjects to state and explain the reasons that they had used for their choices in the survey on preferences for and opinions concerning teaching/learning methods. Analysis of this textual data that is based on human experience is aimed at obtaining an understanding of various factors and their relationships that contributed to the how and why of what has been found within the empirical results in the first part of this study. Details of the evaluation process and the results obtained through content analysis within this second part are reported in the next sub-section. As these open-ended questions were part of the surveys administered within the final online questionnaires, which have already been explained in the first part of this multi-method study, the same study context and conditions of conduct were applied, as delineated in part 1 of this study.

4.3.2 Results and discussion

Of the 313 completed responses that were collected through the surveys regarding student preferences for and opinions about teaching and learning methods, 302 responses were used in the content analysis. The 11 responses where subjects stated that they were unable to answer have been discarded. From these 302 responses, narrative data was extracted related to the open-ended questions asking subjects to state and explain the reasons for making their choices in these surveys. These were then compiled into a cross-linked textual data set, which, after an initial key word and concordance analysis, coding, and forming of meaning units, yielded 408 category entities for 16 basic categories. In order to eliminate researcher-induced bias and a priori assumptions as much as possible (cf. [3,13]), each open-ended response in the survey was reviewed and analyzed by both authors. In this way, two raters were working through the process in combination, and reaching consensus on allocating the meaning of content encapsulated in responses to an individual category through condensation into and grouping of meaning units and codes. Categorization was approached in a mostly bottom-up manner to ensure the creation of data-grounded categories that gave priority to the opinions and views of participants over those of the researchers. However, some top-down oriented elements were also used in the form of preset categories, which captured all meaning units found in responses that could not be associated with valid entities of any category created in the study (cf. discussion on deductive and inductive approaches, for example, in [13,39]). All categories, emergent and preset, were located at the basic level within a category hierarchy and were coherent to superordinate categories relating to the gradually evolving themes of advantages and disadvantages for both tutorial-based teaching and learning from errors, as experienced and articulated from the students' point of view. In particular, seven categories denoted by *T1* to *T7* were created with *T1 – T4* for capturing advantages and *T5 – T7* for capturing disadvantages of tutorial-based teaching. Another seven categories denoted by *E1* to *E7* were created with *E1 – E5* for capturing advantages and *E6 – E7* for capturing disadvantages of learning from errors. Also, a category denoted by *CM* was created to account for responses which indicated that tutorial-based teaching and learning from errors were considered as two complementary methods, while not providing any further details on particular advantages or disadvantages. Finally, a category denoted by *VD* was created to capture all those responses, which, at the time of the analysis, yielded no useful meaning units that could be compiled into a valid category entity for any of the 15 categories that had been created in this part of the study. Of the 302 valid responses, 125 provided a meaning unit that was compiled into one valid category entity, 106 provided meaning units that were compiled into two valid category entities. In the case of the latter, the compilation outcome reflected responses where subjects expressed their opinions on both an advantage and a disadvantage in regard to their teaching/learning method preference. Eventually, these compilations yielded 35 entities related to category *VD*, 36 entities related to category *CM*, 178 entities related to categories *T1-T7*, and 159 entities related to categories *E1-E7*. A brief overview of these categories is given below. A complete, more detailed description of all categories created is reported in the Appendix.

Advantage of tutorial-based teaching:

T1 tutorials are easy to find, comprehend and apply

T2 tutorials support learning of commands

T3 tutorials provide basic modeling knowledge

T4 tutorials aid explicit understanding of errors

Disadvantage of tutorial-based teaching:

T5 teaching value reduction due to availability and dependency of tutorials

T6 tutorials do not support understanding of errors

T7 tutorials do not provide any support for reasoning

Advantage of learning from errors:

E1 support for recognition/identification of critical situations

E2 useful in avoiding the repetition of errors

E3 support for correcting CAD models

E4 support for reasoning

E5 learning value because errors are not usually documented

Disadvantage of learning from errors:

E6 grasping of errors is too difficult

E7 possibility of errors is so overwhelming

Not further categorized yet:

VD Void meaning

CM complementary methods

The overall proportions of category entities related to tutorial-based teaching and learning from errors computed to 52.44% and 38.98%, while those of the *VD* category stood at 8.58%. This indicates that almost 1.4 times as many advantages and disadvantages were provided for the tutorial-based teaching method as for the learning from errors method. Taking a look at the individual categories in regard to advantages and disadvantages, regarding method the proportion of categories indicating a disadvantage for tutorial-based teaching was 17.29%, which was far greater than the 3.15% for learning from errors. In particular, the provision of basic modeling knowledge and the relative ease of finding and applying concepts were the most frequent factors used for expressing an advantage for tutorial-based teaching, as indicated by a proportion of 13.97% for *T3* category entities and a proportion of 11.03% for *T1* category entities. Support for the recognition and identification of critical situations, and support for reasoning were the most frequent factors used for expressing an advantage for learning from errors, with proportions of

16.67% and 11.03% for *E1* category entities and *E4* category entities respectively. Lacking support for reasoning was the most frequent factor used for expressing a disadvantage for tutorial-based teaching, as indicated by an overall proportion of 4.41% for the *T7* category. Among disadvantages for learning from errors, the most frequently stated factor was that it does not make much sense to learn about just a few errors, as there are so many errors and mistakes that can be committed. This was reflected in the 0.74% proportion of the *E7* category entities.

As the compiled data sets of responses from the surveys and opinion polls are all cross-linked, tracing the data provenance of categories and their entities in regard to preference for teaching/learning method and attendance at classes not only helped in revealing further interesting insight but also shed some light on possible causes leading to the outcomes reported above. Category entities were traced back to data compiled from responses in which a preference for tutorial-based teaching was expressed, and yielded results as follows. The most frequently mentioned factors used to express an advantage for this teaching method were related to categories *T1* and *T3,* which had within-group proportions of 30.34% and 23.60% respectively. In particular, within this group, factors relating to category *T1* were mentioned 1.7 times as frequently by subjects who preferred a non-integrated method as by those who prefer an integrated method. In the case of category *T3*, this relationship was reversed based on a factor of 3.2. Also, a few subjects who preferred an integrated method mentioned that the two methods were complementary (category *CM* at 2.25%), while their peers with a preference for a non-integrated method did not express this opinion at all, which is consistent with their choice of preference. Subjects who preferred an integrated method also provided a critical opinion about tutorial-based teaching in the form of disadvantages relating to category *T6*. It was interesting to observe that advantages for learning from errors relating to categories *E1* and *E4* were also mentioned here.

In the case of category entities that were traced back to data compiled from responses in which a preference for learning from errors was expressed, results obtained were as follows. The most frequently mentioned factors used to express an advantage for this learning method were related to categories *E1* and *E4*, having within-group proportions of 17.27% and 24.46%, respectively, followed by category *E2* with 15.11%. In particular, within this group, factors relating to categories *E1* and *E4* were 3.0 and 7.5 times as frequently mentioned by subjects who preferred an integrated method as by those who preferred a non-integrated method. Also, a few subjects who preferred an integrated method mentioned that the two methods were complementary (category *CM* at 1.44%), while their peers with a preference for a non-integrated method did not express this opinion at all, which is consistent with their choice of preference. Interestingly, irrespective of their preference for an integrated method or a non-integrated method, in this case subjects did not indicate any disadvantage in regard to learning from errors.

Some category entities were traced back to data compiled from responses in which a preference for an integrated method was expressed and both tutorial-based teaching and learning from errors were considered to be equally important, yielding results as follows. The second most frequently mentioned factor used to express an advantage for this preference was related to category *CM*, with a within-group proportion of 17.78%. This result was a minor surprise, as category *CM* had been expected to be the most popular choice. However, the most frequently mentioned advantages for learning from errors were actually related to category *E1* (21.11%). The most frequently mentioned advantages for tutorial-based teaching were related to category *T3* (16.11%). Just one subject mentioned a disadvantage related to category *T6* in relation to tutorial-based teaching. However, no disadvantage was mentioned in regard to learning from errors.

Further insight can be gained by analyzing again the results reported above, while taking into account an additional data dimension, namely attendance at classes. A re-examination of the most frequently mentioned advantages for tutorial-based teaching, which relate to categories *T1* and *T3*, shows that, in case of *T1*, which occurred most frequently in responses within the group with a preference for a non-integrated tutorial-based teaching method, only 29.41% came from subjects that had attended all or almost all classes, while the other 70.59% came from subjects who had actually skipped half or more of the classes. In the case of factors related to *T3*, that occurred most frequently in responses within the group with a preference for an integrated method, considering both tutorial-based teaching and learning from errors to be equally important, subjects that had attended all or almost all classes and those who had skipped half or more of the classes showed almost equal contribution rates, at 48.28% and 51.72% respectively. Here also the difference in occurrence of factors related to *E1*, representing the advantages of learning from errors, that occurred most frequently in responses, was less pronounced for subjects that had attended all or almost all classes (60.53%) and those who had skipped half or more of the classes (39.47%) within this group. Opinions related to the advantages of learning from errors, that are associated with category *E4*, were most frequently expressed in the responses of subjects with a preference for an integrated teaching/learning method with an emphasis on learning from errors. In this group, subjects who had attended all or almost all classes used category *E4* related expressions twice as often as subjects who had skipped half or more of the classes. Finally, it should be noted that statements containing the disadvantages of learning from errors, that were associated with category *E7*, were found only in the responses of subjects within the group that preferred an integrated method with an emphasis on tutorial-based teaching and who had skipped half or more of the classes.

4.4 Competency Development Achievements and Teaching/Learning Methods

4.4.1 Specific objective and study design

This part of the multi-method study is aimed at determining aspects of competency development to shed some light on the relationship between teaching/learning methods that were designed and integrated to support development of both positive and negative knowledge and competency and actual learning outcomes achieved with them. Within this analysis, evaluation is approached from two perspectives, each described in detail within one segment in this third part of the study. From the student’s perspective, self-evaluation and confidence are evaluated by analyzing data from surveys regarding self-rated competency and skills in regard to attendance at classes and teaching/learning method preferences. From the educator’s perspective, actual learning outcomes are evaluated by analyzing performance data from tests in regard to attendance at classes and teaching/learning method preferences.

Examination material aimed at determining aspects of learning outcomes related to subject matter was organized as two tests. Those tests were administered as part of a set of online questionnaires, which were designed to compare competency at CAD surface model interpretation before and after the introduction of negative knowledge within the newly developed integrated course structure. The tests were structured for participants to assess the geometric quality of surfaces, identify geometric deficiencies in surface models, and provide an explanation for their evaluation. Participants were also asked to rate their confidence in each answer. In particular, participants were asked to select one option out of five which, according to their best knowledge, most accurately described the geometric condition of each of the surface models in the questionnaires. The provision of an explanation for their evaluation was organized as an open-ended question accepting written comments. Note that in the questionnaires starting from the academic year 2017/18, several new structural features were implemented to enhance overall data integrity and survey data analysis. One such feature was an internal key that links survey responses between intermediate and final data without compromising the anonymity of participants. This improvement allows for the survey and test response data, which are collected within one academic year, to be compiled into a repeated measures design, enlarging the empirical analysis range of various factors and their possible impact on subject groups. These were disconnected in prior studies using questionnaires administered during the academic years 2016/17 and 2015/16.

In Fig.4 an actual example is shown of a geometric/topologically deficient surface-based CAD model, which was used within the questionnaires that were related to the final test. The questionnaires used in the tests were designed to show the students a CAD model with a surface that appears to be smooth-looking with good continuity.


(a) (b) (c)

Figure 4: Examples of surface-based CAD model segments used in the final test. From left to right: (a) CAD model image rendered in ray-traced mode, (b) CAD model image rendered in shaded mode with isocurves, (c) CAD model image rendered in shaded mode with both isocurves and control points.

Its topologically deficient structure is concealed beneath its visually attractive appearance. Representing the CAD model in a ray-traced rendered mode results in a nice-looking image with a reflecting surface, as shown in Fig.4(a). However, a closer look at the CAD model rendered in shaded mode and replenished with isocurves (Fig.4(b)) and with related control points (Fig.4(c)) will reveal to a subject with a certain level of CAD competency the previously concealed topological deficiency in the form of a surface containing a degenerate point. In asking subjects to express their agreement or disagreement with whether the surface has been modeled in the proper way, and thus does not contain any defects or deficiencies, the test questions have been designed to probe not only whether subjects are able to detect and identify CAD model deficiencies, but, more importantly, whether they are able to correctly assess the degree and impact of this type of deficiency, and thus be able to correct the initial impression of a CAD model's visually attractive appearance based on the rendered image. Hence, to prevail within the test scenario as outlined and provide a correct response, subjects need to have developed a certain level of competency and reasoning capacity, enabling them to reach beyond answering CAD domain-related questions based on visual intuitive assessment. Making an accurate and confident assessment of CAD model quality is an essential transferable skill within CAD competency, and one that is seen as an esteemed and desirable learning outcome of this restructured MCAD course, being ranked equal in importance and value to strategic knowledge, and it was therefore chosen in this study in preference to testing specific CAD system related domain knowledge/skills. As the opinion poll on teaching/learning method preferences and the survey on self-rated attendance at classes were administered as a part of the voluntary set of online surveys, as described earlier, the same study context and conditions of conduct as delineated in part 1 of this study were applied.

4.4.2 Results and discussion

Within this first segment of the third part of this study, data were used from the surveys regarding students' self-rated competency, which were administered within the final questionnaires, covering only the past two academic years. This step was taken in order to maintain data integrity, as the structure of this self-assessment survey was altered after the academic year 2015/16, when improvements and modifications were introduced into the scale structure for the competency scores employed in the survey. From the total number of responses collected, as described elsewhere, 198 were used in this first segment, with 101 responses from 2016/17, and 97 responses from 2017/18.

Relating data on self-rated competency to attendance at classes showed a general tendency for an increase in self-confidence regarding improvements in capacity, knowledge, and skills, as perceived by the student, to correlate with an increase in course attendance. This tendency was least obvious for the two cases of being able to correct a CAD model with defects and being able to recognize defects within a CAD model. It was rather modest for the case of being able to plan correct modeling of a surface-based CAD model. However, it was quite pronounced for the case of correctly using a CAD system. In this last case, a statistically significant relationship between self-rated competency improvement and attendance at classes (Pearson's test of independence for $df = 1$, $\chi^2 = 9.317$, $p = 2.270e-3$) was detected. Further calculations for this case revealed that for students who had attended all or almost all classes and who indicated that there had been an improvement in their competency in using a CAD system, the odds were 2.250, while for their peers who had skipped half or more of the classes, the odds were 0.918, which compiles into an odds ratio $OR = 2.450$ with a 95% confidence interval $CI = [1.317, 4.572]$. Additional analysis of self-rated competency data for the case of improvement in using a CAD system cross-classified along with attendance at classes and filtered regarding preference for teaching/learning method, revealed a statistically significant relationship between self-rated competency improvement and attendance at classes (Pearson's test of independence for $df = 1$, $\chi^2 = 5.084$, $p = 2.415e-2$) in the case of students with a preference for learning from errors.

For this second segment of the third part of this study, in addition to data from the surveys on self-rated attendance at classes and preference for teaching/learning method (see again Fig.2 and Fig.3), data were also obtained from two tests related to the evaluation of the quality of surface-based CAD models (see Fig.5), which were administered within sets of intermediate and final questionnaires, as reported elsewhere in this paper. Analysis of the data regarding preference for teaching/learning method that were cross-classified along with correct and incorrect surface model assessment test response revealed a statistically significant relationship between preference for teaching/learning method and test response (Pearson's test of independence for $df = 1$, $\chi^2 = 4.972$, $p = 2.575e-2$). In particular, in the case of students with a preference for learning from errors, proportions of correct test answers were 2.1 times as high as the proportions of their peers in the tutorial-based teaching preference group. Differences of proportion within teaching/learning method preference were even more pronounced. Students with a tutorial-based teaching method preference reached an odds value of only 0.385 for selecting a correct answer instead of an incorrect one, with an odds ratio of $OR = 2.065$. Further analysis based on these data, which were previously cross-classified along with preference for teaching/learning method and test response, and later also filtered regarding attendance at classes, provided some additional insight.

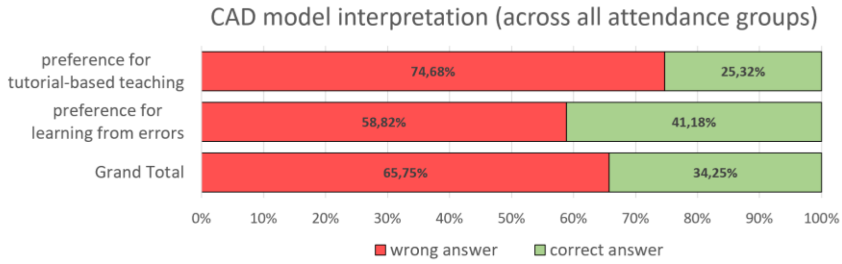

Figure 5: Graphical representation of proportions of correct and wrong surface-based CAD model interpretation responses for preferences of teaching/learning method across all attendance groups.

First, an increase in the odds ratio from 2.065 to $OR = 2.291$ for students having attended half or more of the classes, and to $OR = 2.745$ for students having attended all or almost all classes, has been noticed, which reflects the increasing strength of association between teaching/learning method and positive test response. Second, in those data sets cross-classified along with preference for teaching/learning method and test response, not only did the odds ratios increase within student groups filtered according to increasing attendance at classes, but also the balance order of proportions changed in cases that were related to correct and incorrect test response with students having a preference for learning from errors. For example, as shown in Fig. 6, for the filtered data of students having attended all or almost all classes and having a preference for learning from errors, the proportion of correct test response was 51.79% which was greater than the proportion of incorrect test response (48.21%). This situation was reflected by an odds value greater than 1. However, for those with a preference for tutorial-based teaching, this balance order of proportions was always the opposite across all filtered attendance groups. In other words, the proportion of incorrect test response was always greater than the proportion of correct test response. Hence, the odds values always remained smaller than 1. These observations, taking into account the current data context, can be interpreted as an effect where an increase in attendance at classes is enhancing further the positive relationship between teaching/learning method preference and test performance, in particular for students with a preference for learning from errors.

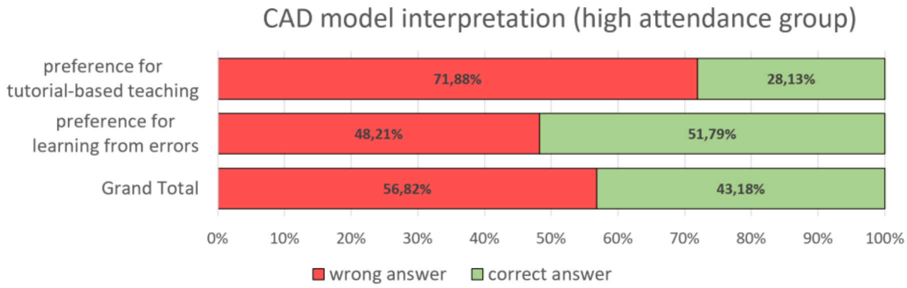

Figure 6: Graphical representation of proportions of correct and wrong surface-based CAD model interpretation responses for preferences of teaching/learning method of the high attendance group.

To also get an insight into the significance and quality of performance improvement, response data from the intermediate test and the final test were compiled into sets of linked nominal data and assessed with respect to two dichotomous variables, namely correct and incorrect test response. Note that due to this study design where linked proportions are based on the same sample of subjects, calculation of statistical significance is related to the analysis of marginal homogeneity of contingency tables with a dichotomous trait, requiring a different statistical tool from the analysis of categorical association for unrelated proportions (cf. [17]). In the analysis detailed below, McNemar's chi-squared test and its related odds ratio are used. Analysis of linked test response data revealed a statistically significant relationship (McNemar's test of marginal homogeneity for $df = 1$, $\chi^2 = 5.000$, $p = 2.535\text{e-}2$) between the test performance of students in the intermediate test and in the final test. In particular, marginal proportions (in regard to correct test response) for the intermediate test (p_I) and final test (p_F) computed to $p_I = 28.36\%$ and $p_F = 43.28\%$, respectively. Discordant proportions (intermediate test / final test) computed to 22.39% and 7.46%, yielding an odds ratio of $OR = 3.0$. These calculations demonstrate an overall performance increase of about 300% regarding results between the intermediate and the final test. In particular, overall correct test response increased from 28.36% to 43.28%, which translates into a 22.39% segment of students who were able to significantly improve their performance. Besides these promising results, there was also a student segment of 7.46% for which, unfortunately, performance went into the opposite direction, and thus warranted some additional investigation, which provided further insight as follows. In one half of the cases, students reported that they had attended only a few classes, or none at all. Here, probably, a simple lack of domain knowledge, as a result of the low attendance rate, can be assumed to be the main cause. In the other half of this segment, students indicated that they had attended all classes, and also had high confidence in their answers to the tests. Content analysis of the open-ended explanations that were associated with these answers revealed that those students provided either an incorrect account for their correct answers in the intermediate test and failed in the final test because they could not apply what they thought they knew for sure, or a correct account for their correct answers in the intermediate test, but failed in the final test because of a wrong account that should have produced a correct answer.

These circumstances indicate that those cases should not be attributed to fortunate coincidences or guessing right, but to false knowledge and an inability to translate knowledge into practice. The dominant factors behind this phenomenon seem to be related to low or no attendance at classes and thus a lack of domain knowledge, and either false knowledge leading to wrong conclusions or difficulties in relating domain knowledge to actual situations.

5 CONCLUSIONS AND FUTURE WORK

The empirical study was based on data obtained from student feedback through online questionnaires, which, structured as surveys and tests, were related to learning outcomes, test performance, self-assessment, and opinions on teaching/learning methods used in the recently restructured MCAD course. The results of this study supported and confirmed outcomes that can be summarized as follows. Evaluation of outcome measures related to test performance in respect to teaching/learning methods used during classes and exercises showed that the number of correct answers in tests improved considerably after increasing the proportion of teaching methods related to negative knowledge development and learning from error examples. Analysis of CAD model interpretation responses in relation to attendance at classes and during laboratory exercises showed that, in the case of the final tests, there was also a relationship between the accuracy rates of CAD model interpretation and self-rated attendance. This indicates an improvement in the capability of the students to correctly perform a CAD surface model interpretation, which seems to be related to the rate of attendance at classes and active participation in laboratory exercises. It is reasonable to infer that a prerequisite for students to benefit from this newly designed course structure is that they attend classes and exercises, and interact not only remotely with the learning material provided online, but also in person during supervised laboratory exercises, in particular those in the second half of the course, where teaching based on negative knowledge and error examples is increasingly used.

Taking into account self-rated competency levels, test performance, and preference of teaching method, analysis of tests and survey responses revealed that the two teaching methods were equally important and useful to students, in particular to those who also exhibited an above average level in self-rated competency and test performance. In general, the number of students who would prefer a non-integrated approach was much lower than the number who would opt for an integrated approach. However, in relation to non-integrated teaching approaches, there was a tendency to prefer teaching/learning methods related to negative knowledge and error examples in the case of responses that could be linked to correct test answers, and a preference for teaching/learning methods related to positive knowledge and tutorials in the case of students whose responses could be linked to incorrect test answers. One possible explanation for this observation is that negative knowledge and expertise are important components of competency, which in turn is reflected in better performance and a more adequate self-rating. Here the former is supported by an increase in certainty as a result of the acquisition of negative knowledge, leading to an awareness of possible negative as well as positive outcomes in regard to strategies and actions. The latter can be attributed to increased reflective capabilities, which are known to be promoted by negative knowledge.

Further investigation provided additional insight into some of the issues highlighted above. This was based on content analysis and evaluation of survey responses in regard to the advantages and disadvantages of teaching/learning methods as experienced and seen from a student's perspective. In the survey, a greater variety of opinion, and a clearer and more detailed manner of expression, was detected in the responses of students who both had a preference for learning from errors and had attended all or almost all classes. In responses across all preferences for teaching/learning method, the number of advantages expressed outweighed by several magnitudes the number of disadvantages, indicating that the restructured MCAD course and the learning experience and learning outcomes it facilitated were perceived positively. It was also interesting to see that students who had a preference for learning from errors, whether they had opted for an integrated or a non-integrated method, could not mention any disadvantages to this method. Their peers with a preference for tutorial-based teaching, however, noted advantages and disadvantages for the components of both methods. Taking into account attendance at classes, it became evident that most of the disadvantages being associated with learning from errors were actually expressed by students who both had a preference for tutorial-based teaching and had skipped half or more of the classes. This empirical finding again suggests that an understanding of and appreciation for learning from errors, and thus developing negative knowledge and competency, requires students to attend classes and pro-actively interact with the study and learning material, which includes interaction with academic supervisors during exercises and in-class discussions.

To further understanding of the qualitative as well as quantitative elements of the learning experience as afforded by the restructured MCAD course, and of factors that influence student opinion, learning behavior, and subsequently also learning outcomes, additional surveys have been initiated and administered along with the tests and surveys as reported in this paper. Within the empirical data collection and analysis that are currently in progress, and furthermore taking into account recent trends in secondary education to increasingly include selected elements of CAD in the curriculum, research in progress aims to shed light on, among other matters, the role of the educational background of students, in particular freshmen and sophomores at institutions of higher education, in relation to the issues outlined above.

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Appendix

This appendix provides a description of the 16 basic-level categories developed from within the content analysis. The basic structure of the categories is described using various combinations of matching definitions, identifying features, typical instances, and atypical instances. Note that the last-mentioned is sometimes explicitly given due to issues related to the typicality of category entities, the varying graded structure of categories, and borderline category entities that may arise.

ID	Name	Category Description
VD	void	Any opinion or sentiment with a meaning unit that cannot be associated with any category regarding the advantages and disadvantages of tutorial-based teaching and learning from errors. Atypical instances include entities obtained from survey responses such as sequences of symbols consisting only of blanks and dots.
CM	complementary methods	Any opinion or specific view that explicitly refers to or reflects on the notion that tutorial-based teaching and learning from errors are complementary methods. This includes specific views related to explanations about learning different things and benefiting in various equally important ways from both tutorial-based teaching and learning from errors.
T1	tutorials are easy to find, comprehend and apply	Any opinion on tutorial-based teaching that relates to advantages expressed through defining features such as tutorials being both easy to find in digital form online and quite easy to understand and go through. Further features that were considered are the more practical nature of tutorials and that tutorials are less demanding for those who are beginners in modeling. The latter is also considered in regard to comments addressing the ease of understanding and replicating both examples and instructions contained in tutorials.
T2	tutorials support learning of commands	Any opinion on tutorial-based teaching that relates to advantages expressed through defining features such as tutorials providing know-how on means to operate and handle CAD systems, or programs, or software, or tutorials helping in becoming familiar with CAD systems, while also providing practical information in the form of commands to use them.
T3	tutorials provide basic modeling knowledge	Any opinion on tutorial-based teaching that relates to advantages expressed through defining features such as tutorials supporting the development of knowledge about geometric modeling, tutorials teaching how to make a model, or tutorials teaching in a step-by-step manner how to approach model creation.
T4	tutorials aid explicit understanding of errors	Any opinion or specific view, which, interpreted as an advantage, explicitly refers to or reflects on the notion that tutorial-based teaching is motivating and engaging, and thus provides incentives to become interested in and learn about errors. Also included are opinions such as that one first needs to participate in tutorials and make errors, before doing anything else, and that tutorial-based teaching motivates learning from errors because errors are not covered in tutorials.
T5	teaching value reduction due to availability and dependency of tutorials	Any opinion on tutorial-based teaching that relates to disadvantages expressed through defining features such as that tutorials are easy to find in information spaces like the World Wide Web, and thus attending classes with tutorial-based teaching has less meaning and educational benefit, and tutorials are focused on a specific modeling procedure. Also, specific views have been included such as that tutorials do not explain the why or give reasons for applying commands and procedures, and therefore what is being taught is limited or restricted to certain modeling situations or systems.
T6	tutorials do not support understanding of errors	Any opinion or specific view that explicitly refers to or reflects on the notion that just following tutorials does not support raising awareness of mistakes and errors or even help in understanding errors, and that this is a shortcoming or disadvantage of tutorial-based teaching.
T7	tutorials do not provide any support for reasoning	Any opinion or specific view on tutorial-based teaching that relates to disadvantages expressed through defining features such as tutorials being focused on or bound to specific examples, for which they provide the *how* to do something, but do not provide the *why* or *how* to plan it, and thus reasoning and strategy development are not supported.

E1	support for recognition/identification of critical situations	Any opinion or specific view on learning from errors that relates to advantages expressed through defining features that are centered around or directly associated with the recognition/identification of critical situations.
E2	useful in avoiding the repetition of errors	Any opinion or specific view, which, interpreted as an advantage, explicitly refers to or reflects on the notion that learning from errors has the potential or capacity, or is useful for, avoiding the repetition of similar mistakes or errors.
E3	support for correcting CAD models	Any opinion or specific view, which, interpreted as an advantage, explicitly refers to or reflects on the notion that learning from errors provides knowledge on and understanding of errors and thus puts one in a position from which corrections to CAD models can be attempted.
E4	support for reasoning	Any opinion on learning from errors that relates to advantages expressed through defining features such as analysis of error examples helping in developing strategic knowledge, or knowing about errors and mistakes making one more confident / competent in planning / approaching modeling.
E5	learning value because errors are not usually documented	Any opinion or specific view, which, interpreted as an advantage, explicitly refers to or reflects on the notion that errors or situations leading to / causing them are neither documented in tutorials and manuals nor captured / reported systematically in any form in information spaces such as the World Wide Web, and thus it is a worthwhile learning experience to see error examples in classes, and learning about errors and mistakes makes it worth attending class.
E6	grasping of errors is too difficult	Any opinion or specific view on learning from errors that relates to disadvantages expressed through defining features that are centered around or directly associated with difficulties and barriers encountered in understanding the examples and material related to errors and mistakes as provided in classes.
E7	possibility of errors is so overwhelming	Any disadvantage of learning from errors that relates to the opinion or specific view that, because the number of errors and mistakes that can be committed is so overwhelming, it does not help, or is not worthwhile, or does not make any sense to be made aware of and learn about, just a few of them.