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

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Introduction:
In various commercial and industrial engineering settings CAD systems are increasingly used on a broad base. In particular, the spread of mechanical computer-aided design (MCAD) systems within the mechanical engineering industry has in a remarkable way increased at both the depth of application range and the technological developments of MCAD systems. The latter have led to considerable complexity in the models to be managed by modern MCAD systems, and an increase in 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. 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 reasons, lead 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 course of educational approach are falling somewhat short in several directions regarding to what is currently expected in the labor market from graduates leaving institutions of higher education to seek employment. Here, from an educational point of view, the issues related to achieve development of 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 of 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 due to the fact that tutorials and best practices usually teach "*what to do*" (positive knowledge), though in many situations being aware of critical circumstances that might lead to mistakes and errors, thus also knowing "*what not to do*" (negative knowledge) becomes equally important to 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 teaching and learning [11]. The design of the 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.[4,10]), 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, and thus increasing the efficiency of problem solving, while additionally promoting the quality and depth of reflection on actions. Now, with the newly developed educational framework in its third year of successfully running within efforts to restructure the CAD course offered at the department where the authors operate, various forms of student feedback embodied in observational records, CAD models, final exam material submissions, and questionnaires were obtained and systematically filed with the intend for post-processing and analysis. Results obtained from the latter are used to gain insight into how far current efforts to restructure the CAD course actually improved learning outcomes as originally planned and how the current implementation of the educational framework is actually perceived by the students in regard to their learning experience and self-evaluated personal competency development. In the next sections following some background, an overview is given on the empirical study and evaluation. Finally, some pointers and a brief summary on the data and results obtained during an empirical study on student feedback based on a set of over 700 collected questionnaires, which will be presented and discussed in detail in a further full-length paper, are provided.

Background and Scope:

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 on how students learn (see also discussions in [1,2,3,8]), a novel approach to improve CAD education has been developed and implemented as follows.

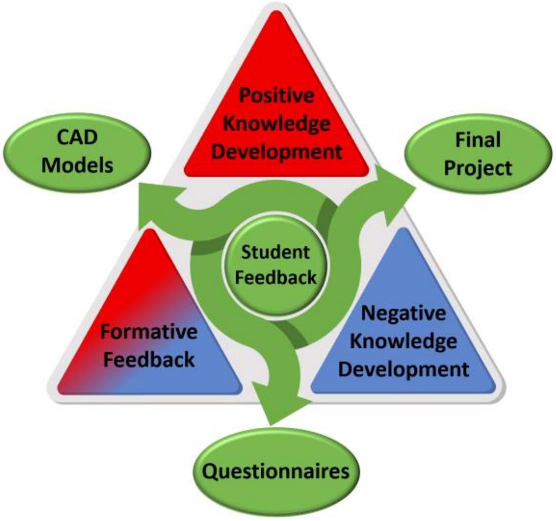

Fig. 1: Overview of structural components related to knowledge development and feedback within the newly developed integrated CAD course.

The approach integrates negative knowledge and learning from errors as crucial elements (cf.[4,9,12]), with traditional teaching methods (positive knowledge) in combination with methods of formative assessment/feedback (cf. [5,6]) 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/built-up are formulated as an element of strategic knowledge (development) aimed at developing 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. These 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, besides traditional lectures and tutorials, various modeling exercises are provided, which are individually designed for different learning aspects. Within loops of formative assessment/feedback that are coordinated with elements of positive/negative knowledge development and learning from errors, results of the exercises are collected and assessed, to identify shortcomings and errors, which usually remain hidden from students due to their limited domain knowledge and expertise. Representative examples of the assessed exercises are later used to discuss, during lectures and also online through the CAD course web site, issues relating to critical modeling situations, model deficiencies and how to prevent them. In certain cases, if feasible, they are also used to demonstrate how to initiate a recovery. More details on the theoretical foundation and the implementation of the teaching approach can be found in [7,11].

Empirical Study and Evaluation:

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, 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 to improve description of and insight into the relationship between the newly developed and implemented approach and its contribution to enhance 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 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 (LMS). Online participation in the questionnaires by students is both anonymous and voluntary. Data collection through the online questionnaires was carried out over the past three consecutive academic years from 2015/16 to 2017/18 involving three different student cohorts. Each student cohort was ranging in the size of about 140 to 160 students.

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. A component within the set of two questionnaires was considered as a form of self-report. One was administered before and the other after the introduction of negative knowledge into the current MCAD course. These served both as a correlational study and as a survey. One part of the study was aimed at self-assessment regarding elements of competency considered as psychological constructs, such as confidence and 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 relate 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 now described in the next sub-sections.

The part of the multi-method study that is aimed at determining aspects of competency development by examining elements of learning outcomes related to subject matter was organized as two tests. Those tests were administered as a 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 identify geometric deficiencies in surface models and to provide an explanation for their evaluation. 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 part of the multi-method study that is aimed at determining aspects of competency development by examining individual sentiments on subject knowledge, abilities, and skills acquired, was structured in relation to performance as tested, and self-rated attendance rate at the classes and exercises. The two self-assessment surveys, which were administered as part of a set of online questionnaires, were designed to compare self-rated competency with actual ability to correctly conduct a CAD surface model interpretation before and after the introduction of negative knowledge within the newly developed integrated course structure.

The part of the multi-method study that is aimed at determining aspects of competency development by examining individual sentiments on teaching methods was structured in relation to self-rated competency and actual performance as tested. The survey, which was administered as part of a set of online questionnaires, was designed to compare personal opinions on the importance and usefulness of teaching methods with both self-rated competency at and actual performance of correctly conducting a CAD surface model interpretation after the introduction of negative knowledge into the newly developed integrated course structure. In the opinion survey, within the online questionnaires, five options were given for expressing an opinion about teaching methods related to positive knowledge and negative knowledge as experienced during classes and CAD laboratory exercises within the newly designed course. The survey was structured for participants to select the option that best described their opinion on the teaching methods used in the course in regard to importance and usefulness of tutorials and error examples. Participants were also asked to rate their attendance at classes, for both lectures and exercises.

<u>Results and Conclusions:</u>

Results of the empirical study based on data obtained from student feedback through online questionnaires, which, structured as surveys and tests, were related to learning outcomes, performance, self-assessment, and opinion on teaching methods used in the recently restructured CAD course, supported and confirmed outcomes that can be summarized as follows.

Evaluation of outcome measures related to test performance in respect to teaching 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 is also a relationship between the accuracy rates of CAD model interpretation and the self-rated attendance. This indicates an improvement in the capability of the students to correctly perform a CAD surface model interpretation, and this seems to be related to the rate of attendance of classes and the 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 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 methods, analysis of tests and survey responses revealed that both teaching methods are 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 preferences for any non-integrated approach remained much smaller than the number of preferences for an integrated approach. However, related to non-integrated teaching approaches, there was a tendency to prefer teaching 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 methods related to positive knowledge and tutorials in the case of responses that could be linked to wrong test answers. One possible explanation for this observation can be attributed to negative knowledge and expertise in that they represent an important component 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 positive as well as negative 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. Besides outcomes already summarized above, the empirical study, in particular the qualitative data analysis, also revealed several additional findings, such as for example, further possible reasons of why students prefer a particular teaching method over another, which are reported in detail in the paper.

References:

[1] Chester, I.: 3D-CAD: Modern technology – outdated pedagogy?, Design and Technology education: an International Journal, 12(1), 2007, 7–9.

[2] Elvira, Q.; Imants, J.; Dankbaar, B.; Segers, M.: Designing education for professional expertise development, Scandinavian Journal of Educational Research, 61(2), 2017, 187–204. https://doi.org/10.1080/00313831.2015.1119729

[3] Garikano, X.; Garmendia, M.; Manso, A. P.; Solaberrieta, E.: Strategic knowledge-based approach for CAD modelling learning, International Journal of Technology and Design Education, 2018, 1-13. https://doi.org/10.1007/s10798-018-9472-1

[4] 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

[5] Hattie, J.; Timperley, H.: The power of feedback, Review of Educational Research, 77(1), 2007, 81-112. https://doi.org/10.3102/003465430298487

[6] Irons, A.: Enhancing learning through formative assessment and feedback, Routledge, Abingdon, UK, 2008.

[7] Mandorli, F.; Otto, H. E.: Negative knowledge and a novel approach to support MCAD education, Computer-Aided Design and Applications, 10(6), 2013, 1007-1020. https://doi.org/10.3722/cadaps.2013.1007-1020

[8] Menary, G. H.; Robinson, T. T.: Novel approaches for teaching and assessing CAD, in: Proceedings of the 17th International Conference on Engineering Education, August 21-26, Belfast, Northern Ireland, UK, 2011, Paper-No.: MO.P.SA 11.228.

[9] Minsky, M.: Negative expertise, International Journal of Expert Systems, 7(1), 1994, 13-19.

[10] Oser, F. K.; Näpflin, C.; Hofer, C.; Aerni, P.: Towards a theory of negative knowledge (NK): almost-mistakes as drivers of episodic memory applications, in: Bauer, J. and Harteis, C. (eds.), Human Fallibility: The Ambiguity of Errors for Work and Learning, Springer, Dordrecht, The Netherlands, 2012, 53-70. https://doi.org/10.1007/978-90-481-3941-5_4

[11] 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

[12] Parviainen, J.; Eriksson, M.: Negative knowledge, expertise and organizations, International Journal of Management Concepts and Philosophy, 2(2), 2006, 140-153. https://doi.org/10.1504/IJMCP.2006.010265