

# Establishing CAD and PDM as part of engineering education in large classes for undergraduate students

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**Abstract** — *Computer Aided Design (CAD) software has become a standard in almost all sectors of mechanical engineering. Users are not only required to be competent with the actual CAD system, but also with the data management and the according IT-infrastructure. Therefore the companies expect experience with such environments from potential employees. In order to meet that requirement of computer skills, students of Mechanical Engineering learn using CAD systems, such as Pro/Engineer and PDM systems, e.g. PDMLink embedded in Problem Based Learning (PBL) at IPEK the Institute of Product Engineering. At the same time student numbers are increasing and more content is integrated in the BSc curricula. An approach to teach over 600 students per semester in CAD/PDM classes is demonstrated in this paper. The students participate in Mechanical Design courses over two years. Starting with hands-on workshops in the first semester, the students work on engineering problems with increasing complexity in teams of five over the second, third and fourth semester. It is described how CAD/PDM tasks are embedded in this PBL approach. This paper explains how the student's private laptops and workstations are integrated in the institutes PDM-infrastructure, since the capacities of available computer pools are far below 600 simultaneous users. Furthermore the technical aspects of the infrastructure are described. As there is only a limited number of at most four CAD/PDM lectures per semester, numerous materials and support services are provided to assist autonomous learning. The setup of screencasts, manuscripts, task sheets, slides, help-desk-hours, expert consulting, mail support, FAQs, newsletters and more is depicted in detail. This paper illustrates the on-going evolution of the CAD/PDM education over the past years, with increasing numbers of students and changing IT-environments. The effects of the recent developments were evaluated by student surveys shown in this paper.*

**Index Terms** — CAD, PDM, Mechanical Engineering, Problem Based Learning

## PDM/CAD IN DESIGN EDUCATION

The utilization of 3D parametric CAD-Software has become a standard in almost all sectors of mechanical engineering. This development has been accompanied by growing possibilities in the field of Computer Aided Engineering (CAE) which goes along with huge amount of data that needs to be handled. This and the increasing complexity in product, process and organizational structures in modern companies makes it difficult to work efficiently. A way to handle this complexity is to control the data and information flow combined with a predefined product structure. Product Lifecycle Management (PLM) is a strategy to address these topics. While PLM is a strategy, Product Data Management (PDM) systems are software solutions to actually implement such a strategy in a company [1]. Therefore companies expect experience with working within such environments and with such software-solutions from job entrants. This demand has been addressed by universities in various ways. In most cases the necessary skills are taught in separated courses and the necessary practice is expected to be gained in following projects.

At some universities very large systems have already been established to supply a lot of users with modern CAD and PDM solutions. The RWTH Aachen with its initiative ProVerStand is supporting about 45000 users throughout the federal state of NRW (Germany) based on the PDM-system PDMLink supplied by Parametric Technologies (PTC) [2]. In various publications ideas and requirements for the integration of CAD and PDM into the education of product development engineers have been expressed. Bitzer et al. has proposed an education concept in which the necessary theoretical engineering background, soft skills and the usage of CAx-systems is taught accompanied by work on projects derived from industrial design tasks [3]. Ye et al. [4] emphasize that not only the mere use of CAD and PDM software should be thought, but more how to actually use it in the product development process.

This has been addressed by Feldhusen in the undergraduate course "Introduction to CAD". Next to a project task supplied by an industrial partner the students from Aachen were teamed up with students from the Korean Hongik University in Seoul [5]. Watty and Binz comment on the experiences with the introduction of project based work in second semester design courses and give an interesting insight on how to overcome heterogeneous team compositions

and to ensure equal learning opportunities [6]. In previous publication of the authors it was shown how different kinds of IT-solutions like CAD PDM and Wikis can be integrated in the education of large amounts of students [11]. It was shown what kinds of challenges have to be faced, what measures are suitable to address them and that the combination with the problem-based learning approach KaLeP is very promising.

## ENGINEERING EDUCATION AT KIT – KALEP

The IPEK - Institute of Product Engineering is an institute of the faculty of mechanical engineering at the Karlsruhe Institute of Technology (KIT) in Germany. The unifying goal of the research at IPEK is to improve product development processes and engineering design education simultaneously in the Humboldtian sense. To this end the Karlsruhe Education model for Product Development (KaLeP) [7] was developed at IPEK. KaLeP is a Problem Based Learning approach and similar curricula are known, e.g. [8]. Besides having classical core engineering skills, design students should also be familiar with modern methods and technologies which they will most likely encounter in their future. Furthermore requirements on graduates in design are continuously increasing, not only for professional skills but also for social skills as well as proficiency with new technologies and methods as current study of the German Chamber of Industry and Commerce shows [9]. The overall goal of the work on KaLeP is to improve design education by addressing these issues with a combination of classic lectures and an accompanying project work within a realistic environment. The evolution and the key aspects of KaLeP are described by the authors in previous publications [10], [11].

The presented work is part of the Mechanical Engineering curriculum at the KIT. During their first four semesters the students have to participate in a Mechanical Design course. The course consists of lectures, tutorials and workshops with project work. An overview of the curriculum is shown in Table 1.

Semester	Lecture Content	Workshop Content
1	Systems Engineering Dimensioning basics Design for X	Gear Disassembly/Assembly Freehand Drawing
2	Elementary component connections Screws & Springs Sealings ...	Dimensioning Technical Drawings First project work
3	Tolerancing Bearings Advanced Dimensioning ...	Second advanced project work
4	Gears Clutches Hydraulics ....	Third more complex project work including Project-Management, cross-team collaboration

TABLE 1  
OVERVIEW OF MECHANICAL DESIGN CURRICULUM

## CHALLENGES IN CAD/PDM EDUCATION

One requirement of the proposed CAD/PDM education is the tight connection to the Mechanical Design courses to assure that CAD/PDM is used for tasks similar to the ones in latter work life and that Mechanical Design lectures are combined with project work within a realistic environment. So in the sense of Problem Based Learning each theoretically taught content is supplemented by practical project work.

The KIT is also facing a growing amount of students, resulting in about 600 students in the current second semester. So the former concept of block course over two weeks is no longer viable. For one the resources for supervising all the students during CAD/PDM courses are not available and on the other hand there would be huge gap between learning CAD/PDM functionalities and applying them to real project tasks. So the intention is to teach the necessary CAD/PDM skill in distributed lectures accompanying the project work.

One aspect of the environment this work is situated in is the heterogeneity of not only the participating students but also the computers they are working on. A survey from 2010 shows that 80% of students estimate their computer skills as good or very good and only about 10% have any previous knowledge of the used software-solutions. So the task is to enable a large amount of students to do their project work efficiently by using the CAD-software Pro/Engineer (Pro/E) and the PDM-system PDMLink. Next to the training with CAD-Software this also means to give them a basic understanding of server-based data-management like checking in and out data and work with revisions. While most of students know what CAD-software is used for, the latter is usually completely new to them.

The second source of heterogeneity is the computers used by the students. While the workstations available at the institute are maintained according to predefined standards, the Institute has no influence on the state of the computers the students are using. Nevertheless the usage of those student owned computers is necessary. The amount of 140 workstations located at IPEK is not enough for two parallel semesters with CAD-usage which consist of about 1200 students. Besides that, this offers the students a more flexible way to do their project work. They can work anytime and

anywhere they want. The range of student's computers is between high-end gaming pcs and ultra-portable netbooks. While most of the students use 32 Bit Microsoft Windows, a growing number is using 64-Bit operating systems and some also manage to run the Linux Version of Pro/E or use MAC OS together with virtualization techniques. Next to that there is a varying range of network bandwidth, starting from 1 or 2 Mbit DSL connections to 1Gbit connections in some computer rooms.

## SOLUTIONS AND THEIR IMPLEMENTATION

As mentioned above the intention of this work is to adapt the achievements in Problem Based Learning to CAD/PDM education. Thus the complete CAD curriculum is today tailored to the Mechanical Design project tasks which are shown in table 1. Among others the most important measure to cope with large numbers of students was to switch from a two week block course to a two year regular tutorial.

In addition to the reorganization of the lecture style, a PDM system was introduced as an important pillar for the CAD education. For one competency with PDM systems are an important skill today and are expected by employers. But additionally the PDM system at IPEK actually enables to tie a network between computer rooms, private computers, education material, project tasks and project results. Students are required to contribute their CAD models in the team related product space on the PDM server.

Year	Students	Course	new Elements
before	100 out of > 100	block course	live session, supervised exercise, slides
2008	300 out of 600	2 block course	+ PDM + textbooks + expert support
2009	all 600	3 semester	+ screencasts + start tool + RSS FAQ + mail support
2010	all 600	4 semester	+ lecture movies + office hours + RSS news
future	all	4 semester	+ release workflows

TABLE 2  
HISTORY AND EVOLUTION OF CAD CURRICULUM

### Curriculum

Today each tutorial is held as an ex-cathedra teaching session of 1.5 hours length between two and four times per semester. The goal of the lecture is to make students aware of certain functionalities in Pro/E and PDMLink and to actually see typical workflows and possible snares with their own eyes. In opposite to teach pure CAD theory the tutorial is always dominated by live CAD operations, performed by the lecturer on his laptop. The shown procedures are explained in the context of the current Mechanical Design project whenever possible.

Whilst the block course was conducted in advance to the Mechanical Design project work at the beginning of 3<sup>rd</sup> semester, the stretched curriculum combines with the recurring project tasks in the last three of four Mechanical Design semesters. Thus the students more likely don't have the feeling to be competent with CAD just after a tutorial session, but learn on the problem throughout all four Mechanical Design semesters. They must prove their skills during the regular project meetings during the last three of four Mechanical Design semesters.

The curriculum at IPEK traditionally includes a broad range of CAD techniques explained in the following and shown in figure 1.

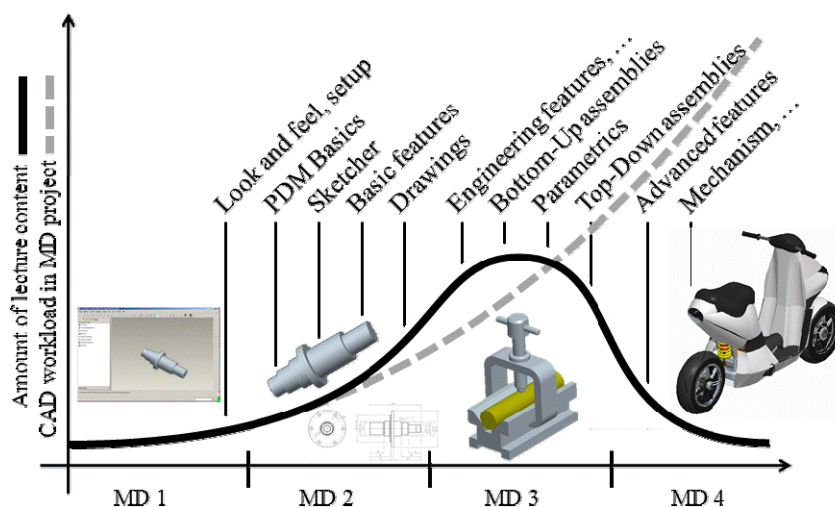


FIGURE 1  
CURRICULUM OF CAD TUTORIAL DURING MECHANICAL DESIGN LECTURE AND CAD WORKLOAD

For most students the handling of engineering software is quite new. In order to overcome one's inhibitions the very first lesson is a "hands on session". Students get explained how to obtain a student edition of Pro/E and how to install the software. Additionally the look and feel of Pro/E and the similarities to common office programs, such as "Open a file", or "Zoom" is explained. The goal is to achieve an immediate feeling of success for every student. Figure 1 also shows the amount of CAD lecture content over four semesters. Clearly the 3rd semester is quite packed with CAD topics. Even though the number of tutorial sessions is reduced from four to two in 4th semester, the amount of CAD activities in project work still increases.

At the end of second semester students are competent to model simple volumes and to derive a proper technical drawing in Pro/E and to use PDM functions on a personal basis. During third semester they learn to set up Bottom-Up assemblies and to use the PDM system for team work. During fourth semester the lecture is ramped down and focuses on Top-Down assemblies and advanced features. At the same time students basically apply all learned CAD and PDM skills in order to design and model a complex product, such as a scooter in 2010.

### Education material

Due to the continuous presence of CAD activities in the workshop and the ongoing CAD tutorials it is required to offer materials for continuous and self-dependent learning. For this reason two **textbooks** have been written, one covering CAD topics and the other dealing with PDM functions. Both textbooks will be supplemented by a tutorial book soon. For quick access to typical CAD/PDM operations such as "sketching" or "check in", **screencasts** about these topics are provided online. A screencast is a click by click display capture with additional on-screen comments and interactive navigation elements rendered as Flash clip. To allow repetitions of live tutorial sessions at home, the display content together with the lecturer's voice and the interaction with the audience is captured and also provided online as **tutorial movies**. All documents are downloadable by the students for free.

During a two year course many events related to the CAD/PDM infrastructure and tutorials can happen, such as server downtimes or changed lecture dates. As students typically do not visit the lecture website frequently, serial mails have been sent, but didn't reach all students because the list of email addresses will never be complete and 100% correct and sometimes mails are recognized as spam. Therefore **RSS news feeds** were introduced. Every student can subscribe to the news feed with any feed reader tool of their choice. The latest messages are even shown in the support software described below.

### PDM and CAD infrastructure

As stated above the current amount of 140 work-stations at IPEK only allows a part of the students to do their project work at IPEK. The solution to this problem is to enable the students to also use their own computers. For this to work several technical boundary condition have to be met. For one the students must be able to access their data which they are working on together from the internet. The external access as shown in Figure 2 to the web-based PDM-System PDMLink enables the students to also work from within the campus wireless-LAN or their homes and is therefore virtually extending the amount of available Workstations. The Institute is also supplying the students with student licenses accompanied by customized installing procedure to ensure, that the local Pro/E installation meets the institutes standards which is introduced below.

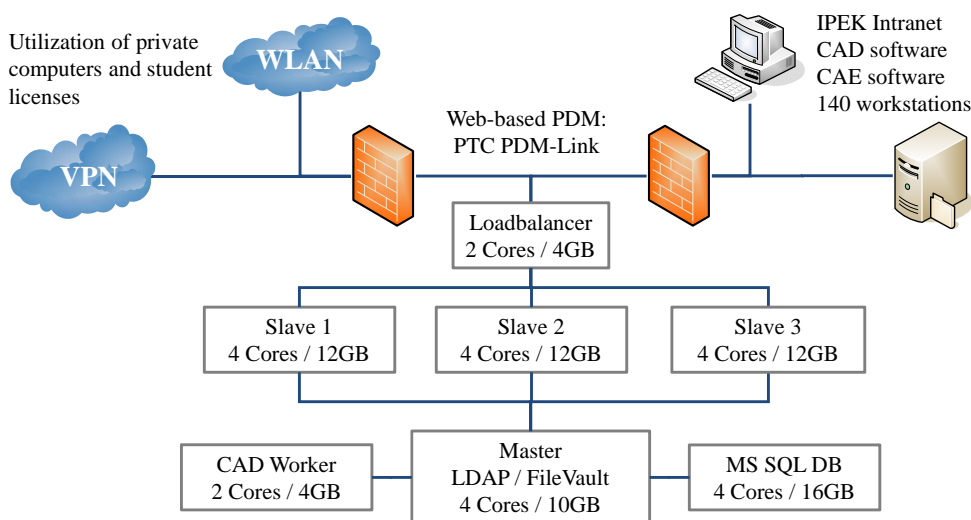


FIGURE 2  
PDMLINK TECHNICAL INFRASTRUCTURE

To enable such a broad Infrastructure, IPEK has been relying on server virtualization for some time. This environment is based on VMware infrastructure. Utilizing VMware has not only facilitated the setup of the environment but also allows adapting to the fluctuating user load.

Currently the Environment consists of a clustered setup as shown in Figure 2. The load balancer is distributing the user request to the three slave nodes, which are responsible for most of the user-interaction and therefore suffer from heavy load during peak hours. The master server is coordinating the slave nodes, responsible for handling CAD data requests and hosts the user data. The CAD-Worker is responsible for generating thumbnails and viewables of the hosted CAD data. The environment can be scaled by increasing the individual system resources but also by increasing the amount of slaves. The third slave is actually only operative during times of high user load, like at the end of a semester when a lot of students are working on large CAD-models. Due to the large amount of users and the high portion of pure CAD users the described infrastructure can be compared to systems which are usually only found in large enterprises.

### CAD start tool

To facilitate a standardized, easy accessible CAD working environment throughout computer rooms and students computers a **CAD start tool** is provided, shown in Figure 3. The tool is installable and executable on a broad range of platforms, such as for example any Windows from XP to 7 on IBM compatible hardware, VirtualBox, Boot Camp, 64 bit systems or netbooks. Since the tool can be set up on a USB pen drive as well, it can be used on any computer without administrator privileges as long as Pro/E is available on the machine.

The tool automatically detects any properly installed version of Pro/E on a computer. Future versions will also have an option to manually register for example network or USB drive installations of Pro/E. Once all presets concerning graphics, language and version are made the tool supports the dial-up to the VPN and eventually the startup of Pro/E with the given configuration. Included in the configuration are options invisible to the students, e.g. server URL, drawing standard, unit system etc.

In addition to the Pro/E start functionality the tool also offers easy access to all IPEK support resources, such as the textbooks, screencasts, lecture movies but also information about office hours and access to the local Pro/E help pages. See figure 3, right side. In order to really reach all students with important news about technical and organizational topics related to the CAD tutorial the tool features a RSS feed reader.

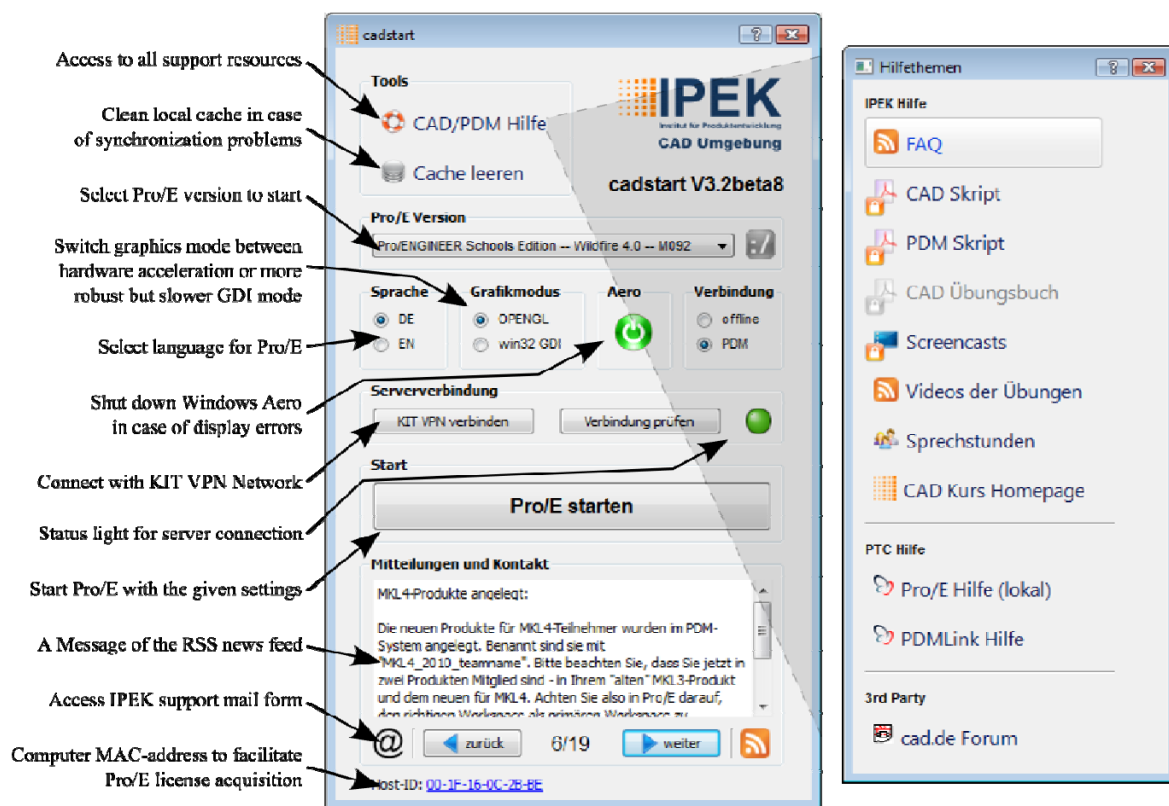


FIGURE 3  
THE GRAPHICAL USER INTERFACE OF THE CAD START ENVIRONMENT

## Support

Whenever students encounter problems with server connection or Pro/E functions, the tool includes a feedback form. Students can enter problem description, contact information and system information. Some system related information is gathered automatically. All data is sent via webpage to cad@ipek.uka.de, thus the students don't even need a mail client on their laptop or, more important, on any workstation on the campus. At IPEK side the form based support mail helps to quickly categorize and answer the mails.

An average answering time for the approx. 30 mails per week is between a couple of hours up to a week according to the problem severeness. Many questions are asked multiple times. Thus a Frequently Asked Question list is provided which is also provided as RSS feed. Students can subscribe to this feed as well and get latest solutions for common problems. The FAQ is also linked directly on the support form, in order to encourage students to read the FAQ before they write a mail.

Even though all content of teaching can be accessed as **textbooks**, **screencasts** and **lecture movies** and besides the **mail support** and **FAQ**, some remaining problems can only be solved face to face with the concerning model opened in Pro/E. So two levels of help-desks are offered: the **office hour** and the **expert consulting**. The latter is once a week and is held by very experienced IPEK staff. The office hour is four evenings a week and is conducted by student assistants. During the office hours students are encouraged to actually work in the computer room and consult student assistants from time to time. More advanced problems are solved at the expert consulting helpdesk.

## VALIDATION OF THE MEASURES

To evaluate the effectiveness of the implemented measures a survey was conducted in summer 2010. It is compared to the results of another survey that was done in summer 2009, before some of the described measures were implemented. In the following the effectiveness of the measures is analyzed and discussed for selected aspects. The answers are specified in percentage of casted votes or with a point range of 1 to 5. (1: very good, 5: very poor)

In 2009 111 out of 190 students participated at the survey while in 2010 190 out of 500 students participated at the survey, resulting in a 55% ratio in 2009 and 35% ratio in 2010. The results are shown by their arithmetic mean. The standard deviation is between 0.9 and 1.3, while the point range was usually fully utilized. The standard deviation is not mentioned for all results. Figure 4 shows the students estimation of their CAD/PDM skills and shows how the previously discussed measures influenced the teaching efficiency.

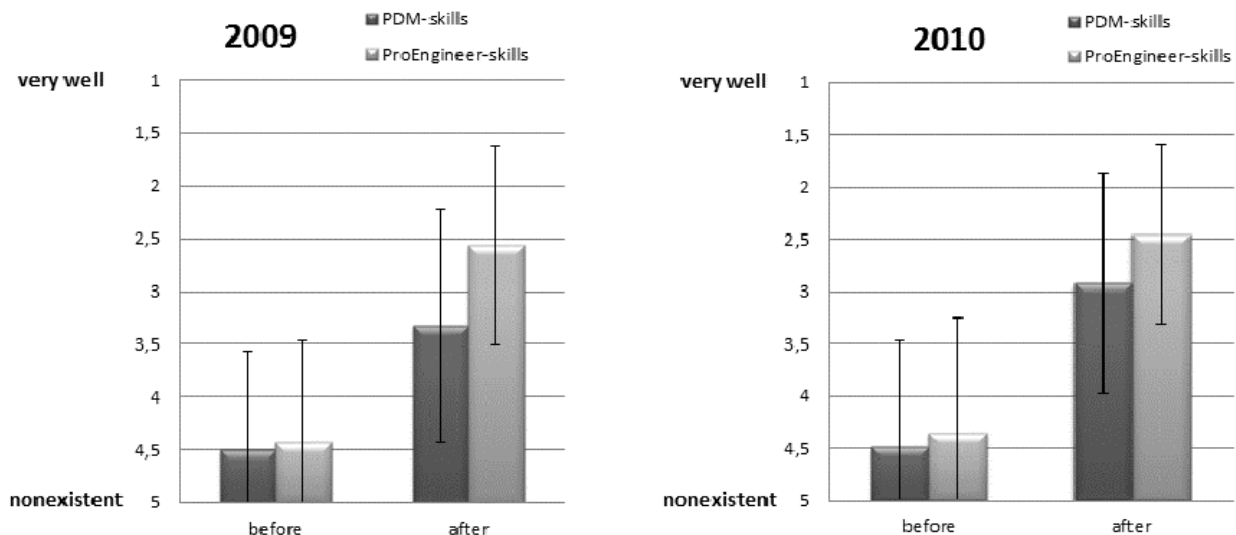


FIGURE 4  
STUDENTS ESTIMATION OF CAD/PDM SKILLS

About 60% of the students declare to have started the course without previous knowledge of Pro/Engineer. Nevertheless more than 50% declare to have coped well with Pro/E within the course. Only 9% of the students had difficulties. Compared to the survey of 2009 the students coped better with Pro/E after the course (2009: 2.57 points; 2010: 2.44 points).

Problems could be observed with the handling of the PDM-system. The students had almost no previous knowledge of PDM-Systems, only 36% declare to successfully work with it and even 28% declare to have made rather negative experiences. Nevertheless there was improvement compared to 2009 (2009: 3.32 points; 2010: 2.93 points).

Considering the rating of the whole approach for CAD/PDM education there can be observed a positive development from a rating of 3.21 in 2009 to a rating of 2.9 in 2010. While only 21% answered with good or very good in 2009, in the current course about 35% did so.

More than 50% of the students would appreciate the possibility of getting to know CAD/PDM earlier in their studies on a voluntarily basis.

### Support

Despite higher participation the rating of the quality of support remained almost the same with 2.34 compared to 2.4 points in 2009. But it can be stated, that less participants use the **mail support** actively in 2010 (2009: 3.55 points, 2010: 3.7 points).

The quality of the **help-desk** sessions gains an overall positive rating. The expert-consulting (once a week) gains a rating of 2.24 points, the evening office-hours (Monday to Thursday) gain a rating of 2.38. The help-desk sessions are used quite frequently by the students, 65.9% of the students visited the expert-consulting at least once and 55.8% visited the evening office-hours at least once. Some of the students used them very intensively (6.0% and 4.3%).

### Education materials

The improved situation on the **education material** – particularly on the **screencasts** – could be a decisive criterion for the decreasing demand for **mail support**. See also figure 5.

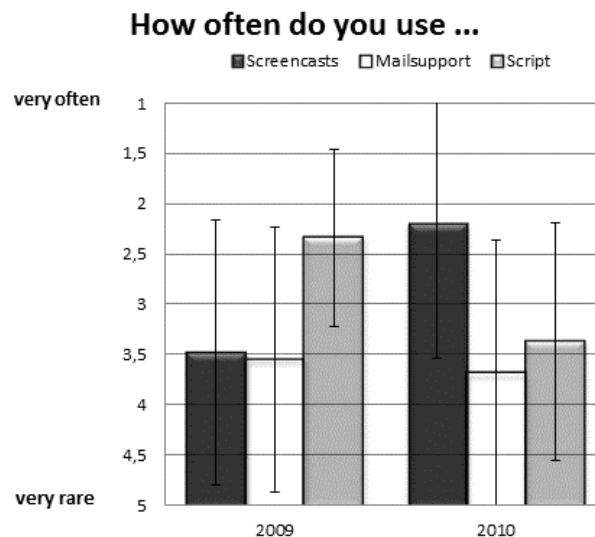


FIGURE 5  
USAGE OF EDUCATION MATERIAL

The new rolled out **lecture movies** are rated positive by 42.31 % but they are watched rather seldom (4.02 points). This might be traced to the intense participation in the tutorial. But at the same time the participants request for lecture movies, which is a contradiction in itself. As a consequence more advertisement for the movies could help to increase their usage. With 1.93 points in 2010 compared to 2.79 points in 2009 the **screencasts** are rated significantly better than in the year before. This can be explained by the increase of available clips per topic and the resulting gain of usage. (2.24 points vs. 3.48 points). The comparison of both surveys obviously shows an interrelation between the usage of **textbook** and **screencast**. See figure 5.

### Curriculum

In 2010 the quality of the tutorials is rated similar to 2009 (2009: 2.75; 2010: 2.58), but the number of participating students in the tutorial has increased. 60.65% state that they join the tutorial on a regular basis, only 2.78 % do not go to the tutorial at all.

42.7% expect to be able to perform the **tutorial** content immediately, even though this is not our main goal of the tutorial, see the **curriculum** paragraph above. In order to prevent frustration by wrong expectations it is important to explain the goal of the tutorial more thoroughly.



## PDM infrastructure

Availability, performance and stability of the **PDM** system at private and institute computers are rated higher in comparison to 2009. Table 3 clearly reflects that trend. This is a result of constant monitoring and tuning of the utilized infrastructure, which enabled better performance despite increasing user load.

	2009		2010	
	privat	campus	privat	campus
availability	3.2	2.36	2.66	2.23
performance	3.38	2.35	2.83	2.35
stability	3.96	2.95	3.25	2.54

TABLE 3  
RATING OF PDM-PERFORMANCE

75.14 % of the survey participants, state that they understood the general purpose of PDM systems. 50.27% of the students observe the PDM system as supporting team work, in comparison to 22.12 % in the survey of 2009. This can be traced back to the simplified handling and the perception of usefulness.

## CAD start tool

A good supporting service is rendered by the **CAD start tool** which is reflected positively with 1.84 points (2009: 2.82 points). The ongoing improvement of the program warrants a high level of acceptance.

## CONCLUSION AND OUTLOOK

Survey results and personal student feedback show, that the extension of CAD education to all students of a Mechanical Design year and the new measures to improve quality, impact and sustainability of CAD training are successful. Although further improvements need to be made to PDM education, so that students gain a better understanding of the PDM-System. Based on the surveys the efforts put in the educational materials the students preferred will be increased. Technically the implemented PDM functionalities in the CAD education only represent a fraction of all the available functionalities like workflows, process-models and release/change process. Obviously it doesn't make sense to overwhelm the students with all possible features of PDM. But there are plans to further ease the evaluation of the students work by using workflows and lifecycle states.

The usage of surveys to validate the efficiency of the CAD/PDM education is also appreciated by the students and will be continued on a yearly basis.

## ACKNOWLEDGEMENT

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