MAPS – A Mathematical Application Project Server

Burkhard Alpers, balper@fh-aalen.de
Fachhochschule Aalen – University of Applied Sciences

Abstract
In this contribution we describe concepts and implementation of a mathematical application project server. The main purpose of the server is to facilitate the work of an instructor who has to identify suitable projects for her/his students. A sample session shows what the server can offer.

1. Introduction

It has been stated quite often that an adequate mathematical education particularly of engineering students should enable them to apply mathematical modeling in solving an application problem of interest. Integrating mathematical application projects (or "case studies") in the curriculum has been identified as one way to achieve this qualification (cf. [2], [5 - 7]). Several examples for such projects can be found in literature, and their potential for motivating and activating students has been demonstrated frequently.

Nevertheless, as far as the author knows, such project work has not been widely integrated into mathematical curricula for engineers. Beside the problem of assessing particularly the work of student groups, a major obstacle seems to be the necessary effort for identifying ever new "good" application projects such that students cannot simply copy the work of former student generations (as is often the case in traditional physics labs).

The work described in this article addresses this obstacle by providing means to ease the work of an instructor to find good projects for his/her students. Our approach consists of:

- Identifying criteria for good projects: for mechanical engineering projects this is documented in [2].
- Identifying project classes: Often, different projects have some common "theme" (like "motion construction" or "signal analysis"); identifying such an underlying "theme" and making this explicit in the definition of a so-called "project class" aims at making it easier for an instructor to find new projects "of the same kind" (like reuse in object-oriented programming from which the terminology is adopted).
- Identifying project instances: Define concrete projects belonging to those classes.
- Providing a web server for classes and instances.

This contribution first describes concepts for such a server that is based on the class-instance metaphor. We identify attributes of projects and classes which are interesting when searching for a particular kind of project, as well as materials which are to be provided in order to help instructors to check whether a project is already or can be made suitable for her or his students. We then shortly describe how the concepts are implemented in the MAPS server; a subsequent example session shows what a user can expect from it. Finally, we compare our work with related efforts by other groups and state some questions that need further consideration.

2. Concepts for MAPS

MAPS is based on the class-instance metaphor which has been adopted from object-oriented software development. As in that area, the essential idea behind this is re-usability. Projects (also called: project instances) are grouped into so-called project classes. A project class extracts the essential aspects and abstracts from the specifities of a concrete project (instance).

For example, a project task might consist of constructing a special motion curve around obstacles fulfilling additionally some properties (restrictions on curvature, e.g.) whereas the underlying project class describes motion design tasks in general. The class description serves to facilitate the process of finding similar projects "of the same kind" by explicitly specifying its characteristics.

The class definitions of mechanical engineering projects currently placed in the server by the author are structured as follows:

- Application background
- Data acquisition
- Mathematical concepts
- Usage of software
- Openness
- Control of effort
- Identification of sub-tasks
- Links and literature

This structure is related to the quality criteria of mechanical engineering projects stated by the author in [2] and can (but need not) serve as a pattern for defining project classes also in other areas (electrical engineering, business studies, …) since it is rather general. In section 4, we give an example for this structure.

Project instances describe specific projects including minor variations. A project instance includes a project description that is handed out to students, as well as materials (if applicable, e.g. a sketch) and a page illustrating results. The latter contains by no means a solution to the project task but it gives an impression of the potential outcome of the project. This is important since the project description is intentionally not too prescriptive since one of the quality criteria is openness. As in real engineering life, the task has to be clarified by group internal discussion as well as communication with the "customer" (here: the instructor). A page called „additional remarks" describes minor variations of the project task and again serves to facilitate the identification of new projects.

In order to give the instructor a quick overview of a possible solution, a corresponding page and additional documents should be provided. The documents might be project reports, Powerpoint slide shows or CAS (Computer Algebra System) worksheets produced by students. One can also provide measurement data which the instructor hands out to students if the necessary measurement equipment is not available.

Note that the usage of the class-instance metaphor is not as strong and formal as in object-oriented software development or programming, and hence the identification of new instances is not so simple. There is no class hierarchy and there might be some overlap between classes such that a project instance could be associated with more than one class. We do not anticipate hundreds of classes, so our approach is a rather pragmatic one emphasising the main intention of facilitating the identification of new projects. There might be even projects in the database with no associated class.

In order to support the search for projects or project classes fulfilling certain criteria, classes as well as instances have searchable attributes. For classes, these are: target group, mathematical topic, application topic. For project instances of which we (wishfully) anticipate to have hundreds there are more attributes in order to offer better search capabilities. These include:

- author, project class, target group

- mathematical and application prerequisites
- mathematical and application topics
- hardware and software required
- anticipated effort, maximum number of participants

Using these attributes, instructors can for example

- ask for all projects dealing with spline functions.
- ask for all projects dealing with motion construction.
- ask for all projects using a certain kind of equipment (“hardware”), e.g. a milling machine if that is available in the laboratory; or ask for all projects where the hardware entry is “none” if no facilities at all are available.
- ask for all projects provided by a certain author.

3. Realisation

From a software point of view, a server implementing the concepts stated in the previous section must have

- database functionality in order to provide attribute storage and query facilities
- web server functionality in order to provide access to web pages, any other kind of documents describing projects (e.g. CAS worksheets), and database queries.

The database part was implemented using ACCESS® where attributes refering to project documents are stored as hyperlinks. Active Server Pages (ASPs) on the web server enable users to query the database via a normal web browser. The web server (or shareware authentification software) can also be used to restrict access to solution material to registered instructors. Currently, a password is needed to browse the solution pages and download solution files like CAS worksheets.

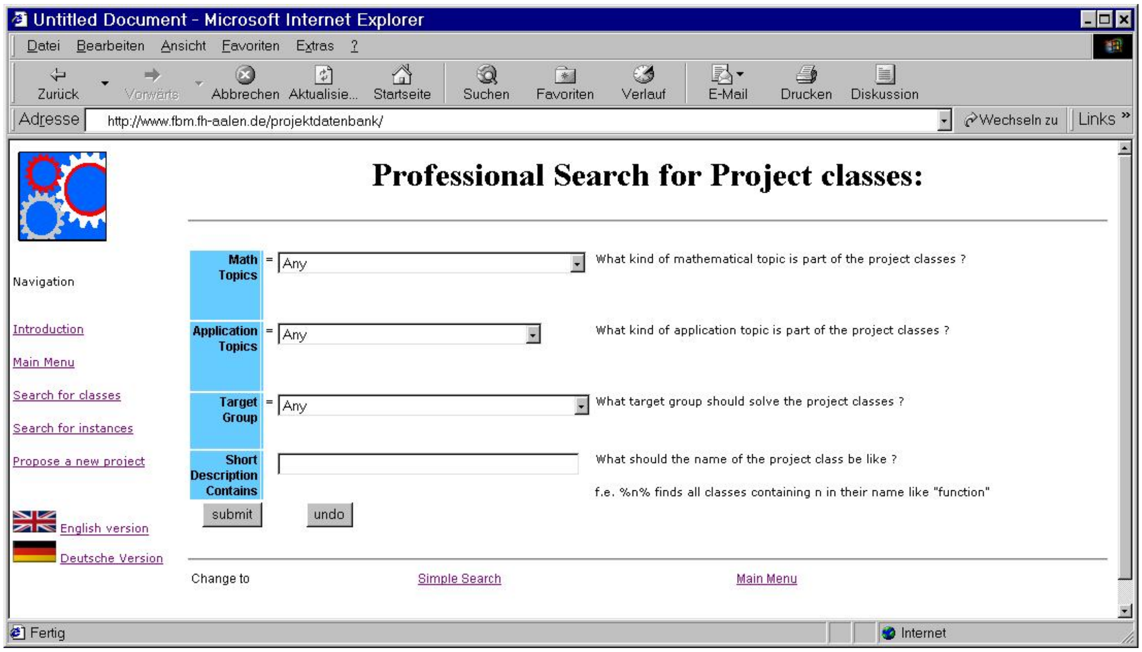
The twofold approach including database entries and virtually any kind of file is very flexible but also has its disadvantages. The database search facilities do not extend to web page content, let alone content of other documents (pdf files, CAS worksheets, …). One could offer additionally a web search restricted to the web pages belonging to the project server. The documents describing a project are either html or pdf files and can hence be accessed using any web browser. For the solution material currently available, at least the documentation was converted to pdf to make it generally accessible. Other solution files require special software like a certain computer algebra system.

The prototype is bilingual (English/German) to enlarge the set of potential project providers and users. This was realised by having both English and German attributes in the database, providing some common pages with combined german/english remarks, and by translating documents which costs additional time. Just for time reasons, the solution documentation was not translated. This is certainly a problem with project reports whereas CAS worksheets are language independent to a certain extent.

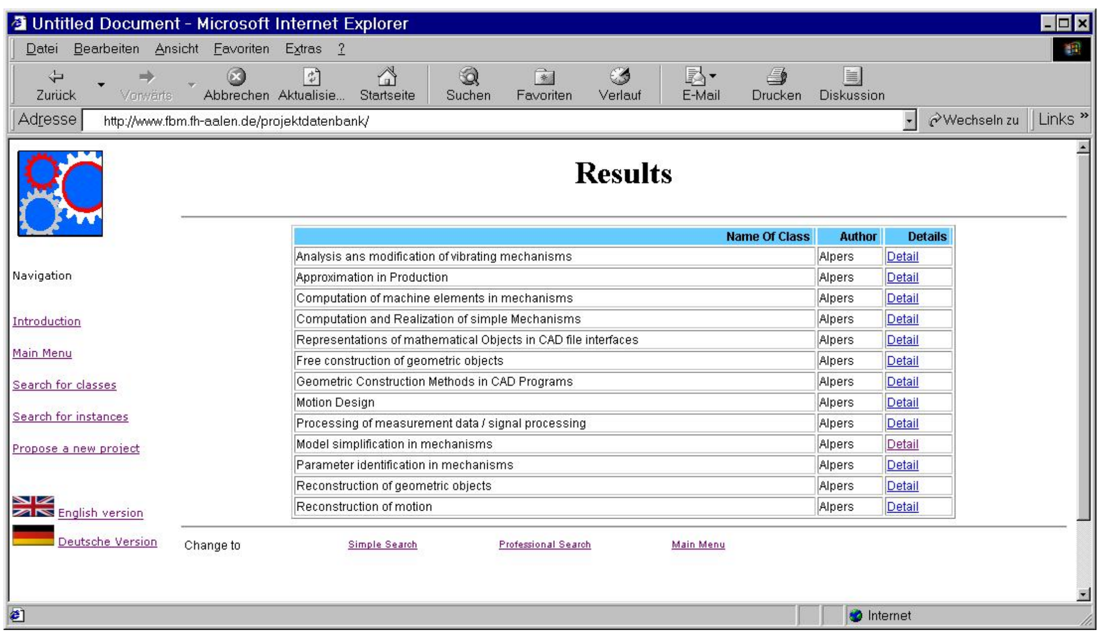
The project server currently contains 13 project classes and 20 project instances. There is a special facility (also based on ASPs) for making new project proposals which are also stored in the database. The database can be accessed at http://www.fbm.fh-aalen.de/projektdatenbank/materialien/allgemeines/introduction.htm.

4. Example

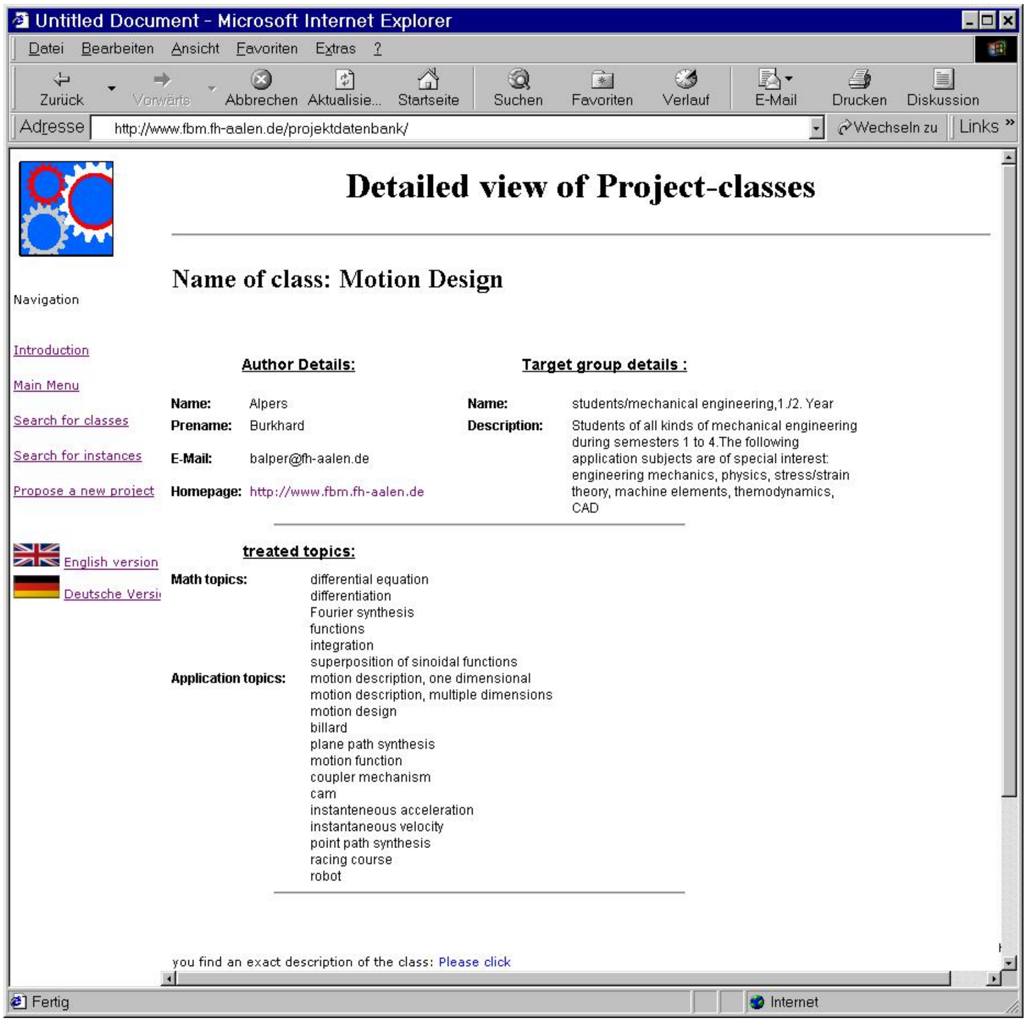
The following screenshot shows the web form for the “professional” project class search (the “simple” version searches only for sub-strings in the class title).



As a result for the query depicted above one gets all currently available project classes:



One can then request more detail on class properties as is shown below for the project class “Motion Design”.



Finally, one can request the full description of the project class which in this case has the following content:

Motion Design (Geometry/Motion curve and Kinematics)

Application background:

Designing motion for machine parts (e.g. in a packaging machine) or in robotics constitutes a central task for mechanical engineers. This comprises the construction of a motion curve (geometry) as well as the definition of a motion function (kinematics). In order to simplify the work, the motion curve can be fixed (e.g. in a linear guiding mechanism or on a given course). Interesting issues for such situations are the maximum acceleration occuring or the time needed to get from one position to another one.

When constructing periodic motions (e.g. in cam design), fourier synthesis is an important method. Here, one approximates an intended motion function by a fourier polynomial such that the occuring frequences are below the first eigen frequency of the moved system in order to avoid resonance phenomena.

Data acquisition:

If the motion curve is given physically, it must be measured. Depending on the curve one measures a set of points or (e.g. on a toy racing course) characteristic data of curve segments (e.g. arc and line segments). Moreover, reasonable restrictions have to be identified (e.g. maximum velocity or acceleration) and measured since otherwise constructed motion functions are not realistic. These data can either be measured or retrieved from information sources like the internet (e.g. for racing course data).

Mathematical concepts:
Mathematical concepts for curves (parameter representation, line and arc segments etc.), interpolation, differentiation, integration (if acceleration functions are constructed first); piecewise-defined functions and aspects of continuity and differentiability; optimization; differential equations when oscillating systems are involved or when computing s(t) from v(s); Fourier polynomials, synthesis; approximation.
The above list of mathematical topics is very comprehensive and it is clear that only a small set of the concepts should be dealt with in a concrete project instance.

Usage of mathematical software:
Motion curves and motion functions are usually given in a piecewise manner. This leads to complex function descriptions which cannot be handled with paper and pencil. But in computer algebra systems (CAS), there are constructs for defining such functions rather easily and then the usual operations on functions (differentiation, graphing etc.) can be applied.
For Fourier synthesis and approximation a mathematical program is also required.

Openness:
Since in general neither curve nor function are prescribed (just restrictions like maximum velocity or acceleration, or obstacles where the motion curve has to go around), there is a broad field for experimentation with functions and for investigating quality criteria.

Control of effort:
The project tasks can be simplified by pre-defining the motion curve or by providing procedures (in a CAS) for constructing motion curves or for transfering motion/velocity/acceleration functions into any other kind of motion related function (e.g. v(s)->s(t)).

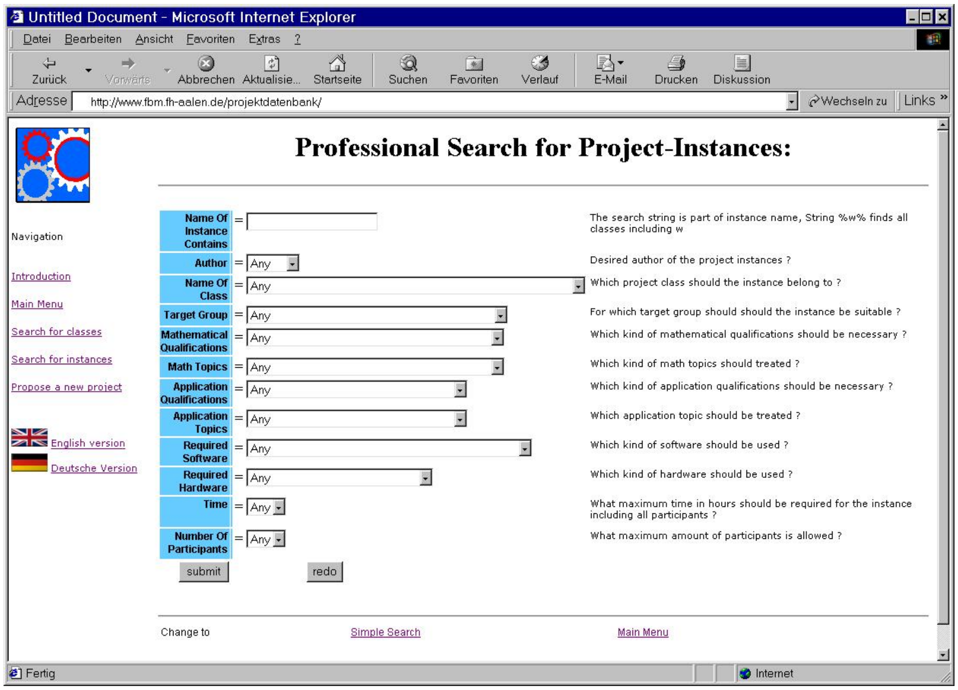
Identification of sub-tasks:
Measurement or retrieval of data (course, restrictions); construction of a motion curve; construction of a motion function; animation or realisation of the motion in a laboratory (if available).

Literature and Links:
VDI-Richtlinie 2143, Blatt 1: Bewegungsgesetze für Kurvengetriebe – Theoretische Grundlagen, Beuth Verlag Berlin 1980
VDI-Richtlinie 2727, Blatt 1: Lösung von Bewegungsaufgaben mit Getrieben - Grundlagen, Beuth Verlag Berlin 1991
Schaeffer, Th.: Systematisches Lösen von Führungsbewegungsaufgaben, VDI Fortschrittberichte, Reihe 1, Nr. 312, VDI-Verlag, Düsseldorf 1999
Lüder, R.: Zur Synthese periodischer Bewegungsgesetze von Mechanismen unter Berücksichtigung von Elastizität und Spiel, VDI Fortschrittberichte, Reihe 11, Nr. 225, VDI-Verlag, Düsseldorf 1995

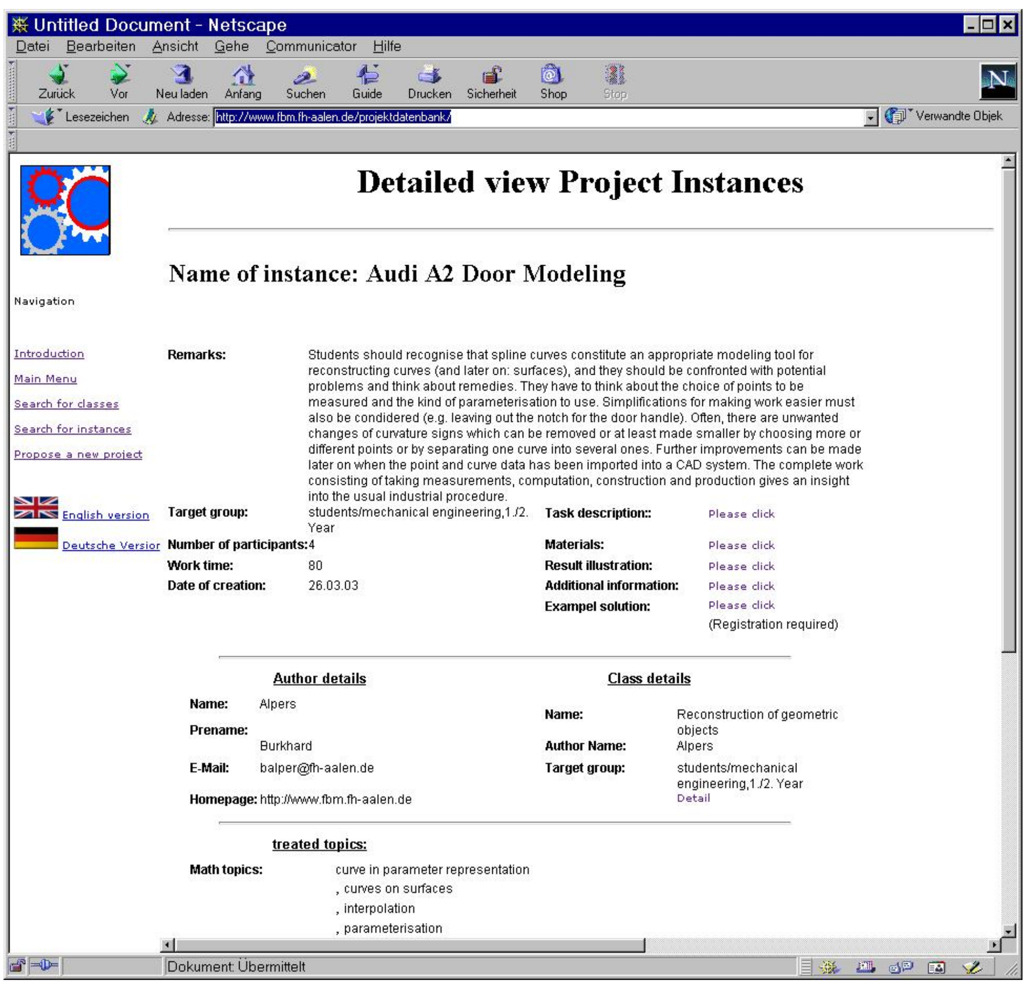
Books on Cam Design and books on robotics.

Alpers, B., Steeb, S.: Flexible Mechanical Engineering Guidelines: A Maple-based Tool for Cam Design, MapleTech Vol. 5, No. 2/3, 1998
Gerny, M., Alpers, B.: Formula 1 – A Mathematical Microworld with CAS – Learning Opportunities and Real Usage, Preprint, Aalen 2002

For searching for project instances “professionally” the following form is offered:



From the result list, one can choose detailed information on one specific instance. The following screenshot gives an example:



The “Remarks” section provides motivational and didactical information. Beside this, data on instance attributes like target group, author etc. are depicted. From this form, one can branch to web pages containing the detailed instance description which is handed out to students, material for the project (e.g. a sketch), result illustrations, additional information (variations of the project theme), and, finally, a page containing links to solution material. For example, clicking on “Task description” provides the following project description:

Project instance: Audi A2 Door Modeling

The surface of one of the front doors of an Audi A2 car is to be measured. For one direction, interpolating spline curves have to be computed, and at the boundary, spline curves should also be computed for the other direction (computation with Maple). The result is to be plotted in Maple. Compute further points on the spline curves and construct an ibl import file for the CAD program Pro-Engineer. Construct a surface in Pro-Engineer and a block having this surface as one of its boundaries. Use Pro-Engineer to produce an NC data file and use this as input for a milling machine.

Clicking on “Additional Remarks” provides some statements on how the project task could be varied in order to create a new project or to adapt it to the environment of the instructor (student qualifications, machines available etc.):

Additional Remarks

In this project, the mathematical computation part is restricted to curves for reasons of complexity whereas in the CAD program surfaces are produced from curves.

The ibl format is an ASCII format that essentially contains point row coordinates (cf. the example solution for a sample file). This format is specific to Pro-Engineer. If another CAD program is used it must be checked whether this program has an ASCII point interface. Alternatively, point data can be plotted as dxf file in Maple.

The following alternative descriptions could also be chosen (according to emphasis, available time, qualification of project workers):
- The computation of spline surfaces can also be performed in Maple.
- Production can be omitted if there is no milling machine or no lab engineer for providing support.

The page on “Result illustration” provides – beside some Maple and CAD – plots a picture of the produced part:

Finally, the page called "Example Solution" contains an outline of how one could proceed when working on the project as well as links to the project documentation, the Maple worksheet and the measurement data all provided by a student group.

5. Comparison with other work

There is a variety of project-related material spread over many books particularly on modeling and applications (cf. [1, 3, 4]) which are valuable sources for finding projects. The German ISTRON group, for example, publishes a series on materials for mathematics education connected to reality. Literature on project oriented study courses (cf. [2, 6, 7]) also contains examples and guidelines on application projects. The problem here is that the material is not readily accessible and searchable by an instructor looking for new projects.

One of the most comprehensive collections which now also offers query facilities is the set of UMAP modules maintained by COMAP (Consortium of Mathematics and its Applications, www.comap.com). This collection contains hundreds of modeling modules which have been set up and tested since 1980. More recently, so-called ILAP modules ("Interdisciplinary Lively Application Projects") have been added (cf. http://www.projectintermath.org/). The modules are meant to support instruction units and activities oriented towards modeling and applications but still need some work for turning them into project definitions. The query facility offered separately on the "MathModels" page (http://www.mathmodels.org/) gives access to about 30 modules. It offers the following search criteria: keywords, student level, problem level, problem source, applications, recommended experience, area of mathematics. As can be expected, there are strong similarities to the criteria used in MAPS. The attributes currently used in MAPS are more fine-grained in that they specify application and mathematical topics in more detail (e.g. "spline function" vs. "calculus"). Whether the finer or coarser approach is more useful can only be decided by users of both databases. As in MAPS, problem (or project) specifications are relatively short and coarse, some background information is provided, and for some problems worked out solutions are presented (without password protection). Moreover, new problem proposals can be submitted via a web form.

The main differences between MAPS and the MathModels server is its emphasis on supporting the instructor in finding ever new projects by applying the class concept, providing minor variations on the instance level, and allowing any kind of solution material. Moreover, whereas many of the UMAP modules are still specified as instruction modules, MAPS provides explicit project definitions. Since the author is mainly occupied with teaching undergraduate mechanical engineering students, the current projects and project classes in MAPS put special emphasis on technology and laboratory integration which is reflected in project attributes and corresponding querying possibilities ("software, hardware used").

Another valuable source of information for setting up projects are the web pages of CAS companies, e.g. the Maple Application Center (www.mapleapps.com) or the Mathematica Infocenter (http://library.wolfram.com/infocenter/). Again, a considerable effort is still necessary to turn the CAS applications presented there into project definitions for a specific student population.

6. Conclusions

It is the main objective of the mathematical application project server presented in this article to facilitate the integration of such projects in the mathematics curricula in particular of applied subjects. For this the server contains project classes which help in identifying many instances, as well as concrete project instances with several documents including solution files. The server is not meant to replace other valuable resources for finding mathematical modeling and application tasks like COMAP/UMAP but is particularly suited to identify group projects in a technology rich environment including both mathematical programs and laboratory equipment.

The bilingual approach serves to enlarge the circle of potential contributors but also has its problems since bilinguality requires considerable additional efforts. Even in the current version, not all solution documents are available in both English and German. It is open whether a completely bilingual server can be maintained. Another open problem is concerned with quality assurance. Some kind of reviewing mechanism should be implemented in order to avoid erroneous material and provide possibly even more variation ideas.

Acknowledgement
Many thanks go to Marten Weber, student of mechanical engineering, who implemented the database and the active server pages.

References
1. *Abel, H., Klika, M., Sylvester, T.:* Materialien für einen realitätsbezogenen Mathematikunterricht, Bd. 7, Hildesheim: Franzbecker (Schriftenreihe der ISTRON-Gruppe) 2001.
2. *Alpers, B.:* Mathematical application projects for mechanical engineers – Concept, guideline and examples, Borovcnik, M., Kautschitsch, H. (Eds.): Technology in Mathematics Teaching, Vol. 2, Proc. ICTMT 5 (Klagenfurt), Wien: öbv&hpt 2002, 393-396.
3. *Dossey, J. et al.:* Mathematics modeling for today's mathematics classroom : a contemporary approach to teaching grades 7-12, Pacific Grove: Brooks/Cole – Thompson Learning 2002.
4. *Giordano, F., Weir, M., Fox, W.:* A First Course in Mathematical Modeling, Pacific Grove: Brooks/Cole – Thompson Learning 2003.
5. *Mustoe, L.R., Croft, A.C.:* Motivating Engineering Students by Using Modern Case Studies, Int. J. Engineering Education 15, No.6, (1999), 469-476.
6. *Niss, M.*: University Mathematics Based on Problem-Oriented Student Projects: 25 Years of Experience with the Roskilde Model, Holton, D. (Ed.): The Teaching and Learning of Mathematics at University Level. An ICMI Study, Dordrecht: Kluwer 2001, 153-165.
7. *Wilkinson, J.A., Earnshaw, H.:* Embedding Mathematical Skills for Engineers: Projects for Engineering Mathematics, Hibberd, S., Mustoe, L. (Eds.): The Mathematical Education of Engineers III, Proc. IMA Conference April 2002, 133-138.