Concepts for the integration of NDT courses into the academic curriculum of universities

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Abstract
Since the application of non-destructive testing techniques becomes more and more attractive in engineering there is a demand to integrate instructions about the basic principles into the academic curriculum. This paper deals with the integration of courses, exercises, seminars and several other elements into the Bachelor and Master curricula at universities. These concepts can be different from the well-known level-courses offered in the non-academic world since they should address also the development of new techniques and applications in a research driven environment. There are several aspects making NDT courses unique compared to other topics. Since NDT is truly interdisciplinary, the courses can be offered separately for different degree programs and disciplines but also as multidisciplinary courses for students in civil, environmental, mechanical or electrical engineering programs, just to name some. While elements of NDT are already included in most of these programs at universities throughout Germany and Europe this is not done in a coordinated way. There is a close relation to topics like measuring techniques, data mining and statistics. First elements of NDT can already be integrated in Bachelor courses and a more comprehensive education can follow in the Master classes. Another specialty of NDT is the easy integration of data driven experiments and simulations using sophisticated measuring devices and sensors as well as complex software what makes such courses very attractive to students. The paper will give recommendations for a curriculum and for several elements (conventional and multi-media) that could support the education of students in the field of non-destructive testing. The recommendations will consider the actual situation in Germany and Europe but can be applied also elsewhere.

Keywords: teaching, courses, lectures, exercises, seminars, moodle, media, wiki

1. Introduction

The so-called Bologna process reshaped the qualification process in the framework of European higher education. It established a set of regulations how to determine the competences of the students and what they should know and being able to do on completion of a course or of their bachelor’s, master’s and doctoral degrees. The framework makes use for two of them (bachelor and master) of the European Credit Transfer and Accumulation System (ECTS), where a certain amount of ECTS points is required to obtain a bachelor’s or a master’s degree. The modularization of degree programs represents a key element of the Bologna Process [TUM 2014]. The module system, e.g. the grouping of courses into thematic blocks, was introduced in an effort to increase transparency, facilitate the transfer of credits between institutions and, in turn, foster mobility within the European Higher Education Area. It was also introduced to improve the quality of the education limiting the number of dropout students. The module system was designed to provide students insight into the connections between subjects within thematic areas, as well as relationships between different thematic areas, and to ensure that student performance is continually assessed throughout the course of study.

What does this mean for the education in the field of NDT? Modules on NDT— no matter what type of instruction and learning process is addressed, like e. g. lectures, exercises,
seminars, projects, self-study, homework, essays, e-learning units – require to follow these rules of modularization, module description and performance assessment in form of an examination. Students who successfully pass an examination completing a module are awarded credits (ECTS points). The number of credits awarded for a module reflects the student workload required for the module.

The key point to perform an educational module is the module description. This should be guided by four elements (Figure 1) and the following questions:

- What learning outcomes is the student to have achieved upon completion of the module?
- What teaching and learning methods will be employed to achieve these outcomes?
- What content is the module to communicate?
- How is students’ achievement of these outcomes to be assessed?

![Figure 1. Four elements of a module description](image)

In this context modules for Non-destructive testing has a lot to offer and all of the mentioned ways to teach and learn can be addressed, including teaching elements like lectures, exercises, seminars, projects, self-study, homework, essays, e-learning units and excursions.

2. Teaching elements in the context of NDT

The afore mentioned elements will be addressed in the following sections separately while the reader should keep in mind that only a combination of the individual elements can form a full module that is equivalent to of e.g. 12 ECTS. Following the definition of the ECTS system above representing the workload of an element, a lecture with three hours plus exercises with one hour per semester week will be equivalent to e.g. 5 ECTS only. Therefore, a single element cannot form a full module which is usually combined by different lectures or exercises. If, after successful completion of the module, students are to be able to conduct NDT measurements independently, lecturing alone is not an adequate teaching method for such an NDT module. Instead, a combination of teaching methods would be better suited to achieving the intended outcomes by providing students guided, hands-on experience through which to acquire laboratory and in-situ NDT skills.

A key focus of the Bologna Process is the shift in orientation of education to outcomes. Assessment in the form of coursework and examinations plays an important role, here, but not as a means of testing students’ ability to merely internalize module content. Competence-oriented assessment measures the student’s attainment of clearly-defined disciplinary and extradisciplinary learning outcomes at the level appropriate to the module and degree program. This is only possible when both the content and method of assessment are “aligned” with the learning outcomes of the module. The so-called “constructive alignment” (Figure 2) was the basis for the design of NDT teaching elements at TU Munich.
Since no concept or best practice paper for the integration of NDT content into the curriculum at German universities exists, the following descriptions are based on the practice at the Technische University München and the Chair of Non-destructive Testing. All examples are taken out from the daily work with the students.

2.1. NDT lectures

The content of NDT lectures and also the tools that are supporting the teacher and the students (resp. their learning outcomes) have to be selected according to the following points:

a) Field of application (for example civil, environmental, geotechnical, mechanical or electrical engineering, architecture)

b) Expected level of expertise (bachelor or master or post-doc level; introduction, beginners, experts)

c) Time slot available (regular time slot per week per semester, consecutive courses, block courses)

d) Number of students (group work, homework, etc.)

e) Resources available (assistants, measuring devices, computers, samples etc.)

There is a big difference between courses given in physical presence of the students and so-called Massive Open Online Courses (MOOCS) that offer unlimited participation and open access by students via the web. MOOCS are not further considered in this paper but are of increasing importance.

2.1.1. Content

It is obvious that a large variety of combination of the boundary conditions that are mentioned in the above list exists that are governing the content of an NDT course. As an example one possible content will be given in Table 1 for both a lecture on NDT in civil and on mechanical engineering for a 3 hours per week per semester (3 SWS). Such a lecture is accompanied with exercises (e.g. 1 SWS) with hands-on activities of the students using the individual techniques after each lecture. Some topics like impact-echo are relevant only in one particular field (here: civil engineering) and accordingly a cross is set only there.
Table 1. Content of an NDT master course for students in civil and mechanical engineering, resp.

<table>
<thead>
<tr>
<th>Type of the content</th>
<th>Content</th>
<th>Civil Eng.</th>
<th>Mech.Eng.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction and Basics</td>
<td>Introduction and motivation</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fields, waves and particles</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Elastic wave propagation</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Electromagnetic wave propagation</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Data processing techniques</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sensors and measuring principles</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>NDT techniques</td>
<td>Visual Testing</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ultrasound</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Impact-echo</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RADAR and microwaves</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Infrared thermography</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Radiography and CT scanning</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Eddy current testing</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Penetrant and magnetic particle testing</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Potential field mapping</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other handhold techniques</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Acoustic emission testing</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Vibration analysis techniques</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Structural health Monitoring</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Applications</td>
<td>Selected applications in Civil Eng.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selected applications in Mech. Eng.</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

The average number of weeks per semester is fourteen. The twenty-one individual topics in Table 1 can easily fit into such a scheme considering that some topics do not need a full lecture day. A 4 SWS lecture plus exercises will result in 42 hours total time (14 x 4 x 45 minutes). This time quota reveal that a one-semester course can be a “beginner course” only. Expert level courses require consecutive courses and a larger involvement of homework and exercises.

2.1.2. Teaching tools

There are numerous ways to support a lecture and the teaching and learning methods. If the presentation consists of powerpoint slides (what is a fact in most cases) a simple way is the distribution of copies of the slides. The existing NDT course at TU Munich consists of about 1500 slides what illustrated that this way of dissemination is second best. Moreover are good slides not loaded with text but should underline the spoken word by pictures or graphs. A reader can in most cases not understand a content without listening to the spoken word. As a general rule there is no compulsory attendance for students enrolled to a certain lecture. So, how can content be provided in a way that students can work at home? Following educational traditions a comprehensive scriptum (lecture notes) is offered at TU Munich to students of NDT courses (Figure 3). It follows closely the structure given in Table 1 and has today about 250 pages [Grosse 2015]. A translation of the scriptum into English is under preparation.
A written scriptum is useful for the preparation or wrapping-up of a lecture at home. To support a successful reception of the content during the powerpoint presentation several tools like group work or blackboard exercises can help but involve usually a minority of the students only. They are inefficient for large groups. A more modern way is the use of live feedback systems.
The one used in NDT lectures at TU Munich is the web-based PINGO system (Peer instruction for very large groups) developed by the University of Paderborn [PINGO 2015]. This tool is free of charges for universities and based on the interaction using a certain website that is provided by the instructor (i.e. professor). For interaction the students can use their own tablet or smartphone. Figure 4 demonstrates how a PINGO question can be integrated into a powerpoint presentation.

**Figure 4. Integration of a web-based PINGO question into a lecture slides**

The results of a PINGO survey with comparison of classes from 2013 (light blue) and 2014 (dark blue) – B and D are wrong answers.

**Figure 5. Results of a PINGO survey with comparison of classes from 2013 (light blue) and 2014 (dark blue) – B and D are wrong answers**
The students insert the given number (top left) into the window of the website (top right) and can select one (single choice) or multiple answers in a given time interval (usually 1-2 minutes). Usually the students accept this live feedback system because it is anonymous and praxis oriented. It is certainly a valuable tool for the teacher since it is simple to be used and fast. The lecturer can get into discussion with the students easily and see, if a point was understood or not. Even the development of the students can be investigated by repetitive questions and a comparison with former classes is possible – see Figure 5 where the bars indicate the chosen answers of different classes.

Other additional instruments for teaching and learning are the use of multimedia content and Moodle platforms (http://moodle.de/). Moodle – as offered by TU Munich – provides a virtual online classroom that can be used for communication and additional materials like documents, books (from the electronic library), work sheets and many more. This virtual classroom can be used by the students at any place and time and by the lecturer the content can be uploaded once and reused for the next course.

2.2. Exercises

An invaluable tool to strengthen the skills of students in the field of NDT are exercises. The way exercises can be integrated into a lecture or as more or less independent hands-on laboratory measurements depend strongly on the number of students enrolled for a course and the provided resources (see d) and e) in section 2.1). In case of unfavorable conditions with a large number of students and little resource exercises in a classroom using equipment with an LCD projector interface can be used. Examples of such devices are tiny IR cameras (Figure 6), eddy current, ultrasound impulse-echo devices, RADAR, video endoscopes and other handheld devices. Some of the mentioned devices are wireless what increases the applicability for lectures in large halls in front of many students. NDT devices using miniature sensors like Microelectromechanical Systems (MEMS) or can be combined with a smartphone are also available.

![Small IR camera](image)

Figure 6. Small IR camera that is powered via an USB interface and hooked-up to a computer that can provide a video signal for an LCD projector in a classroom

However, a better way to train NDT measurements are individual or grouped hands-on exercises. There are two ways this is done at TU Munich. During exercises for master classes...
some experiments are done together with the lecturer or an assistant (Figure 7). Problems like defect detections and localizations can be treated in deep. The lecturer can help in unexpected situations or with new and unknown specimen. Even very challenging tasks can successfully be examined and mistakes can be analyzed together. This is a more demanding way to organize an exercise because the students learn to analyze a problem, select the best technique, device and sensor and conducting own measurements finishing with a deep analysis and interpretation of the data.

A less challenging way to organize NDT exercises is suitable for a more routine training and suitable for many groups and even for bachelor classes. After a short introduction about the fundamentals of NDT the students are provided with video courses demonstrating a typical measurement (Figure 8) along with a description of the basic settings of the instruments.
In addition a notebook (printout) is provided with a repetition of the basics (e.g. about ultrasonic measurements) and precisely described measuring tasks. 2-3 students are grouped together at their individual exercise day conducting the measurements without supervision (Figure 9). The final results are written into the notebook at the individual topics. The notebook is at the end of the course a document similar to an assessment protocol for each student. This procedure was established by Gehlen and Spengler in 2014 for the bachelor’s “practical course on construction materials” (Praktikum Konstruktionswerkstoffe) with big success. A part of this course are measurements with three individual NDT techniques (ultrasound, RADAR, IR thermography or alternatively endoscopy). Figure 8 depicts a snapshot of one of the training videos that are made available to the students before the course starts.

![Figure 9. Students detecting defects in a car front hood made out of CFRC using lock-in thermography – the measured data are displayed on the screen in the lower right corner (© Astrid Eckert, TUM)](image)

2.3. Seminars

Traditionally a seminar is a way to tackle a topic (e.g. a certain application or method) more comprehensively. The “NDT seminar” as it is organized at the Chair of Non-destructive Testing since 2011 at the TU Munich is a combination of external seminar talks by experts and student presentations. An expert talk is followed by questions that the students have to answer in written form. The topics of the student talks are assigned at the beginning of a semester and chosen from a list provided by the chair. A list of former talks (since 2012) can be found on the webpages of the chair ([http://www.zfp.tum.de/index.php?id=45](http://www.zfp.tum.de/index.php?id=45)).
2.4. Self-study, homework, wikis

For certain study lines (Vertiefungsrichtungen) additional work load and credit points can be provided by tasks that a student can treat at home or at the university aside the lectures. Homework is an example for such a task with the drawback that (at least in former years) the finished homework (even if very well done by a student) disappeared in the desk of the lecturer. A Wikipedia style “NDT wiki” is the attempt to avoid the drawbacks of homework and to motivate students. Wikipedia (https://www.wikipedia.org/) is known as the free encyclopedia that anyone can edit. At the time being the English Wikipedia version contains about 5 million articles. The idea was to compile an own wiki for the field of NDT where students can provide articles during a homework with the aim to compile a more or less comprehensive database on NDT methods and applications. The NDT wiki (“ZfP-Wiki” http://zfp.cbm.bgu.tum.de/mediawiki) is accessible (readable) by everybody but articles can be provided or changed only after permission by the chair. Figure 10 gives an example of one of the student’s articles on CT scanning. A point that is brought up often in regard to Wikipedia is the quality of the articles. In regard to NDT one can prove that some articles of the free Wikipedia encyclopedia contain mistakes, containing statements that are different between different language versions and are less consistent. It is the secondary aim of the NDT wiki to keep full control of the content, put in more consistency and, primary, to provide students with higher motivation for articles that are worldwide readable and will not disappear after the end of the semester.

Figure 10. Snapshot of TU Munich’s NDT wiki at http://zfp.cbm.bgu.tum.de/mediawiki
The NDT wiki is at the time being with 76 individual articles still in its infancy containing exclusively articles in German. But it is continuously growing and will have English equivalent articles (with the same content) in future.

2.5. Excursions

At the Chair of Non-destructive Testing credits may also be awarded for modules requiring forms of qualification other than graded examination, such as participation in a study-related excursion. This gives insights into professional NDT labs and confronts students with real-world problems. A typical NDT excursion consists also of an overview of the company, the actual employment status and typical career examples of NDT employees. There is time enough to answer individual questions and to have private conversations.

![Figure 11. Bachelor, Master and Ph.D. students visiting the NDT group at Siemens AG (Munich) in 2014](image)

Over the last years excursions were organized to visit the NDT groups of the companies Airbus Helicopters, MTU, Siemens (Figure 11) and BMW Group.

3. Conclusions and Outlook

The field of Non-destructive Testing provides interesting and unique topics for certain areas of education. First of all NDT is related strongly to materials sciences to provide insight into material properties and deterioration processes. As a truly interdisciplinary science NDT help to identify problems across several material classes, disciplines and applications. NDT methods are involving measuring, data processing and sensing techniques as well as computer science and simulation. All these skills are beneficial for many disciplines and successful students gather abilities that are useful for many employers. In Munich it is a fact that students from an increasing number of different study lines enroll for NDT courses including...
civil, environmental, geotechnical and mechanical engineering as well as medical, aeronautic
and automotive engineering. This should encourage other universities to establish NDT
courses on a level and for applications that are suitable for their special field of education.
Several already existing courses [Grosse 2013] should be enhanced.
However, no best practice paper is at the moment available as it is for example the case for
the education in the field of construction materials [Reinhardt et al. 2000]. Further efforts
should be made to provide universities and lecturers with concepts to establish such courses.

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References

Grosse, CU [2013]: „Konzepte für die interfakultative Lehre im Fach Zerstörungsfreie
Prüfung“. In: Baustoff und Konstruktion (Eds. Nothnagel & Twelmeier), Springer publ.
Berlin Heidelberg, pp. 359-374

Grosse, CU [2015]: “Einführung in die Grundlagen der Zerstörungsfreien Prüfung im
Ingenieurwesen – Grundlagen und Anwendungsbeispiele“, Technische Universität München,
Lehrstuhl für Zerstörungsfreie Prüfung, 250 p.

PINGO [2015]: "Peer Instruction for very large groups", University of Paderborn,

Reinhardt, HW et al. (Ed.) [2000]: „Hochschullehrer-Memorandum Werkstoffe im Bauwesen –
universitäre Lehre und Forschung“. In: Bauingenieur 75, N0 11, pp. 723-729.

TUM, Academic and Student Affairs Office [2014]: „How to Write a Module Description“. Technische Universität München, Version 2 of November 2014.