Developing a Concept Inventory Tool for Engineering (CITE) Final Report

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1 Abstract

The project aimed at developing a concept inventory that assesses the acquisition of important concepts and program goals of the Electrical Engineering program. The consistent use of such a test would provide students with feedback on where there are on their learning path in relation to the wider context of their program; teachers with a way of monitoring the students' progression towards reaching specific program goals and a possibility to adapt teaching; and the program board with an effective tool for evaluating course content and the structure of the program in relation to the program goals.

2 Project plan

2.1 Problem description

The Higher Education Ordinance (1993:100) regulates the learning outcomes of programmes, such as e.g., Electrical Engineering. Program-specific goals, which specify the students? required competences and knowledge at successful completion, are outlined in the educational plan. To guarantee program goal fulfilment, these need to be connected to the goals of the courses taught within the program. However, while course goals are examined in relation to each course, the program goals are not directly linked to specific examinations. Course goals are indeed typically assessed only once, and there is currently no systematic assessment of the students' retention of skills and concepts between courses. This creates problems at three different levels:

- For the program board: Programs are designed by organising courses in a particular order based on the course goals. This placement is nonetheless made without evidence, i.e., without the aid of quantitative data that evaluate the retention of course goals. This is because this type of data is not available: examinations usually test the acquisition of most concepts only once, and even if certain concepts are tested repeatedly in different courses, examinations are not standardised, and it is impossible to evaluate the learning gains. Hence, program boards typically do not have tools for understanding which concepts are actually acquired (and possible forgotten) by students during their studies.

- For teachers: Typically teachers have no structured and standardized tools for assessing the students' actual pre-existing knowledge before the course starts. One may assume that the course goals of earlier courses have been acquired, but this means neglecting the "forgetting effects". Teachers need to adapt their courses in relation to what the students know but currently these adaptations are made on the fly as the course is taught and not based on pre-identified knowledge gaps.

- For students: Since knowledge and skills are typically assessed in individual courses, the focus is usually on course goals rather than program goals. While this can help focussed learning, the risk is that students are not aware of the bigger picture, i.e., the requirements for completing the program and the overall program goals.

2.2 Aim and purpose

Concept inventory tests, such as the "Signals and Systems Concept Test" [5] or the "Force Concept Inventory, [3] are pedagogical tools that help assessing the acquisition of concepts, and they have been typically used within single courses. The goal of this project is to prototype a concept inventory that spans the entire program of Electrical Engineering, and with this build a tool for assessing numerically the long-term acquisition of program goals. (Electrical Engineering was chosen because S. Knorn, K. Staffas and D. Varagnolo currently teach within this program at UU and LTU, and have studied similar programs.) The purpose of the project can thus be summarised as

- For the program board: i) allow for an improved monitoring of the students' learning, development and achievements in the program; ii) achieve a better insight into which concepts are learned or forgotten by the students at certain times during their studies; iii) provide numerical data for evaluating and, if necessary, adapting the program; iv) allow for an evaluation of the effectiveness of changes in the program through an examination of how the students' results change over time.
- For teachers: allow a better insight into which concepts can be assumed to be known or must be taught again before teaching their courses.
- For students: i) achieve structured, continuous, and comprehensive feedback about their learning gains and progress in the program; ii) gain an increased awareness of the overall learning goals of the program.

The aims of the project, each associated to a specific part, can be summarised as

- Aim / Part 1: develop a comprehensive concept inventory that examines the knowledge of key concepts included in the program Electrical Engineering as well as its program goals.
- Aim / Part 2: develop a strategy for the implementation of systematic concept inventory tests in the Electrical Engineering program.
- Aim / Part 3: develop tools and strategies for presenting the results to the program board, teachers and students in order to allow each group to gain insight in a suitable way, e.g., tailored to its needs.

2.3 Personnel

The project was conducted jointly at UU and LTU and was led at UU by Steffi Knorn and Kjell Staffas and at LTU by Damiano Varagnolo and Eva jällström. The project also involved the program boards and program managers for Electrical Engineering at UU and LTU, teachers in the programs, the University Pedagogy Centre at LTU and student representatives from both UU and LTU.

3 Theoretical background

In order to successfully complete their degrees and be able to operate as independent actors in their field, engineering students need to acquire specific procedural and conceptual knowledge. In this paper we focus specifically on the development and assessment of conceptual knowledge, i.e., understanding the underlying principles of core concepts, since previous studies and our own teaching experience have highlighted that these are areas of concern. For example, Surif et. al. conclude in [4] from problem solving tasks and interviews that most students are weak in conceptual knowledge. Cracolice et. al. also found in [1] that most students employ mechanical algorithms as problem-solving techniques, i.e., memorize the necessary formulas of processes without learning and understanding the concepts. These findings are in line with our own experiences as we have observed that students often struggle to understand fundamental concepts or fail to retain their understanding between courses.

Assessment in the form of traditional written exams is commonplace in engineering education. Unfortunately, a drawback of such exams is that they predominantly assess procedural knowledge, i.e., the ability to complete a specific calculation or task. Limited attention is paid to assessing the students' understanding of fundamental concepts. Moreover, exams are generally designed to assess the goals of specific courses rather than overarching program goals. Finally, the results from individual exams do not provide students with a clear picture of their own progression over time, and it is difficult to use the results from these examinations for pedagogical development purposes since they provide limited insights into the students' retention of skills and concepts among courses. Currently, there is no data available that can provide a holistic view on how students develop conceptual knowledge throughout our programs. *The identified need is, hence, for tools for assessing engineering students' acquisition of important concepts throughout their studies that can be of use for students and teachers and form a basis for educational development activities.*

4 Implementation and method

The three parts of the project were executed in parallel during Autumn 2017 and Spring 2018. Communication was facilitated via email, phone calls and personal meetings with program managers, program boards, teachers and student representatives in the program (hereafter "stakeholders"):

4.1 Part 1: (develop the questions in the test)

At the beginning of the project, it became apparent that it was necessary to first create a common understanding and agreement on i) which concepts were included in the program in general and in the courses specifically and ii) which concepts should be included in the test in case not all concepts could be fit in.

In order to answer these questions, the "courses-concepts-matrix" (CCM) was developed. As a first step, we propose to start by identifying a preliminary list of concepts from the goals and the descriptions of all the courses of the program under consideration and from feedback from the teachers of these courses. After compiling this preliminary list, the importance of the identified concepts are ranked for each course using point scales (e.g., 0 to indicate "not relevant for the course", 1 as "included in the course material" and 2 as "significantly important for the course". For instance, if a concept is included in the course goals of a course, 2 points should be selected).

After identifying the concepts, that should be included in the test, by analysing the CCM, suitable questions were developed by conducting a literature survey on existing concept inventory tests for different areas, studying the course and program plans and goals of Electrical Engineering and getting insights from students studying in the program.

4.2 Part 2: (develop a system for how the students should take the tests)

Planning to implement a CITE requires to take several important decisions. We started our work on this project by listing various options and their advantages and disadvantages.

Which option should be chosen as for when implementing the test will greatly depend on whether the test will be compulsory or voluntary. In case voluntary participation of the students is intended, getting students' feedback in order to find suitable options for them is essential to motivate participation. Hence, we conducted a survey about the different options with over 100 students both at UU and LTU and discussed the options and our proposed solution with the program board.

4.3 Part 3: (understand how to process test results)

It is a crucial step to decide how to handle and use the collected data so that it will be useful and significant for all the various stakeholders. The interests of the stakeholders might be in conflict. We started with evaluating and listing various options and their advantages and disadvantaged. The student survey mentioned above was then also used to receive students' opinion and feedback about the options. The options and the student feedback were then discussed in the program board.

5 Results

5.1 Part 1: (develop the questions in the test)

A CCM was generated for Electrical Engineering at UU and LTU. Both a teacher version as well as a student version was completed. The student version was generated by students from the respecting programs at UU and LTU and reflects a first insight into their perception of which courses were treated with which weight in the courses. Here, it became apparent, that the students' perception does indeed differ from the the course goals and/or teacher's perspective. This created a new research direction, which we will investigate in the future.

Based on comparing the CCM for UU and LTU and interviewing students in the program, we compiled a list of 30 concepts, that are deemed most essential in the program.

Then, several alternative questions for each concept were developed. For this, we closely worked with student representatives from UU and LTU, who proposed questions. Unfortunately, students' difficulty to think conceptually proved to be an obstacle here and developing *conceptual* questions rather than *factual* or *procedural* questions was difficult. Further, most concept inventory questions are not easily available online and more time than planned was necessary to retrieve copies of useful tests from their respective authors. Hence, the final versions if the questions need to be revised over the years as teachers and students gain more experience with the test and the questions.

5.2 Part 2: (develop a system for how the students should take the tests)

We listed the following options to implement CITE:

The most important question is to decide whether participating in the test should be voluntary or compulsory for students. This decision must be based on legal considerations, wider practical consequences (e.g., how to enforce a compulsory test and ow to deal with potential resits in this case) as well as expected outcomes based on feedback from students, teachers and the program board. In case the test is to be made voluntary, it appears to be advisable to investigate which options are most suitable to motivate a large number of students to participate in the test. For this, asking students for their opinion on various options seems to us a valuable strategy. Options could include: getting various forms of informative feedback on the their performance (also over time), plus the results being used to improve the teaching and the structure of the program or small benefits in kind.

Various time planning issues have moreover to be considered. First, there is the need to trade-off between short times, that do not demand too much time from the students but prevent assessing a large span of concepts, and long tests, that allow posing a large number of questions and thus gather detailed data. Similarly, there is the need for understanding how often to take the test. The least demanding option from students perspectives is to take the test once a year but more detailed date would be available if the test would be taken once every term or even four times a year. Finally, yet another issue is to decide when the test should be taken: the option that most likely would allow teachers to best adjust their teaching based on the test results is to take the test right before the start of each teaching year/term/period. However, this time may be occupied with regular (re-)exams. In this case it is reasonable to assume that students would be inclined to prioritize their exams. Instead, tests can also be taken during the first teaching week of the year/term/period, which might inflict less stress onto the students.

Based on the student feedback, feasibility constraints and discussion with the program board, the following options were found to be a good compromise:

1. voluntary participation for students
2. students fill out the test online in a computer lab by giving students code on the day in the room (potentially using paper copies to be filled initially if online system is not available yet)
3. as part of a course or independent during standard scheduled time
4. the test is taken once every term (twice a year)
5. the test is taken at the beginning of the term (during the first week)
6. the test takes 2 hours

In order to motivate the students to participate, they are several options, which would be well appreciated by the students:

- provide fika, coffee or even lunch (if possible),
- give access to results and results history for students to monitor progress,
- tag questions with key words so that students get feedback on which kind of concepts/topics they need to improve,
- do not count or use the test result towards the students' academic record,
- choose a convenient time (for example, not 8am or 3pm) and
- ensure that teachers and program board get and use data in an anonymised version.

5.3 Part 3: (understand how to process test results)

The aspects to motivate students' participation above also indicate some important findings regarding how the data should be evaluated. The following issues seem to be of primary importance for the students: i) the results should be only available in an anonymous fashion to the teachers and the program board, ii) the results should not count towards any academic record such as exam scores or course completion etc, iii) the feedback should be as constructive and informative as possible and hence at least include information on which concept questions were answered correctly or incorrectly and iv) results should not be comparable or introduce a ranking among students.

Discussing this further with the students and the program board, we conclude that these requests should be respected in order to make a clear difference between CITE and ordinary exams. After all, since some problems of ordinary university exams motivated and led to this exact project, it would seem unrealistic to aim to mimic it in CITE or repeat their shortcoming.

Further, teachers and the program board did not see major obstacles in accepting these terms. Rather, the mere existence of anonymous, statistical data for a given cohort (for instance, per study year) is already appreciated and deemed very helpful to improve teaching.

Technically, we further developed several tools to facilitate easy data analysis in Matlab as soon as data are available.

6 Conclusions and future plans

It is clear that implementing concept inventory tests on regular basis may provide numerical evidence for better understanding where the students have problems and enact a series of activities / corrective actions that promote deep learning. We foresee that if a significant amount of information becomes available for teachers and program boards, then this will significantly help developing / revamping courses and parts of the program.

During the project, we interacted with many different students and teachers in the program and the program board. Through this, we received a lot of valuable feedback, which we incorporated to a large extend. Further, it seems that this project has touched a nerve with all stakeholders and perception of the general idea was overall positive. Hence, we believe that CITE should indeed implemented in the electrical engineering programs at UU and LTU and that doing so would benefit all stakeholders.

As a next step, measures should be taken to implement a CITE in a preliminary fashion in order to record first data and gain more experience. This should then used to revise the test, its questions and its implementation further.

When preparing the CCM, we first intended this to be a simple tool to select the concepts to be included in CITE. However, the CCM quickly became a project on its own. We believe that future work should also focus on developing and analysing the various CCMs further. For instance, comparing CCMs for the same programs at different universities, both nationally and internationally, will likely spark an important discussion about what we actually want our students to learn in our program etc. Further, detailed analysis of differences between teachers' and students' versions of the CCM might be an important tool to improve teaching and learning in the programs. Indeed, when presenting our work at some conferences, such as Reglermöte 2018, or discussing it with fellow teachers at our universities, such as with the IT department at UU, the CCM was found to be of huge interest to our colleagues - sometimes even more so than the actual test.

7 Reporting of the results

We have used several opportunities to report our work, which include the following.

- We wrote a peer reviewed conference paper, [2], to be presented at the 12th UKACC International Conference on Control (special track on engineering education) (September 2018).
- We wrote a peer reviewed conference abstract to be presented at NU2018 (October 2018).
- We presented a poster at Reglermöte 2018 (June 2018).
- We presented a poster at TUK 2018 - Teknisk-naturvetenskapliga fakultetens universitetspedagogiska konferens at UU (March 2018).
- We gave a talk at Högskolepedagogiska Konferensen at LTU (June 2018).

All works above were authored by Fjällström, Knorn, Staffas and Varagnolo, where the authors are ordered alphabetically.

Referenser

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