Knowledge ladders
Final Report

This project was conducted by André Teixeira, Steffi Knorn and Kjell Staffas at Uppsala University (UU) together with Damiano Varagnolo at Norwegian University of Technology (NTNU) in Trondheim.

1 Abstract

This project aimed at improving the understanding of how the content and connections between courses in a program contribute to the program learning objectives (PLOs) as well as how they are connected within the program. For this, we developed methods to understand, describe, analyse and visualise connections between the taught contents (such as facts, concepts and procedures), teaching and learning activities and course goals of courses and the PLOs, as well as the relation between courses. We also investigated in which way this is able to simplify communication between students, teachers and the program board in order to increase the quality of teaching.

2 Project plan

2.1 Problem description

Ensuring high quality in teaching includes several important aspects. While some depend on the teaching and learning activities, others depend on the interplay between courses and the overall program design. One such important factor, that heavily influences how well students may achieve the overall program learning outcomes (PLOs) is how well the courses in the program and their contents are aligned in between other courses and with the PLOs. One major problem to realise such alignment between PLOs and courses is a lack of methods to easily understand these connections. For instance, PLOs are often formulated rather vague and abstract. In contrast, students and teachers are mostly concerned with which facts, concepts and procedures (FCPs) are conveyed in the course and are included in the course goals.

When it comes to aligning courses within the program, much depends on the will and effort individual teachers put in to understand which prerequisites can be expected and which learning outcomes are needed for later courses. Merely extracting such information is often difficult, since there is no clear representation of the interfaces between courses. Further, even if one teacher makes the effort of considering all relevant information in his/her planning of the course, this will only work as long as other teachers keep him/her informed about changes in the future. This is usually not done and almost an illusion when teachers change. Also, these activities are complex, time-consuming, typically uncoordinated, and do not involve all the stakeholders simultaneously. This hinders quality assurance and facilitates the emergence of problems such as program incoherences. Additionally, this incentivizes students to take course-centered perspectives, since they have little overview of how different courses relate to the overall program and to their future careers needs.

In summary, we see the following major obstacles and inefficiencies related to:

- lack of awareness by students and teachers of how courses fit in the overall program;
- lack of overview by boards and teachers of how the coherence of the program ties with seemingly minor revisions of individual courses;
- lack of a common language helping teachers and students to communicate with boards.

2.2 Aim and purpose

There is thus a need for tools and methods that support quality assurance in the program design and maintenance, while involving, empowering, and facilitating communication among all stakeholders. In the context of improving the strategies for managing program contents, we targeted the needs of increasing the awareness of students, teachers and program boards on the program contents, and of simplifying quality assurance activities. In essence, in the project, we created methods and tools that aid understanding how Teaching and Learning Activities (TLAs), Intended Learning Outcomes (ILOs) of individual courses and PLOs intertwine in the program. More precisely, our main objective is to help:

- STUDENTS to understand how the contents of different courses connect and expand on each other;
- TEACHERS AND BOARDS to improve their awareness of how course contents flow within the program and contribute to the PLOs;
- ALL STAKEHOLDERS to establish a common language, simplifying communicating needs and concerns.

We thus aimed at ideating, developing and testing new methods for

- Understanding, analysing, describing and visualising connections between FCPs in and PLOs, ILOs and TLAs;
- Understanding, analysing,describing and visualising how different taxonomy levels of FCPs expand and depend on each other during individual courses and the overall program. (For example: In order to reach the level "understanding" of the concept Eigenvector, the level of "applying" of the concept linearity is required.)

In order to develop and test such methods, we investigated central FCPs in the BSc program Electrical Engineering (EI) due to the fact that (i) all involved teachers are teaching in the program and (ii) we have gained significant and useful insight into the program and its structure in our previous work. See for example the CITE project (funded by PUMA in 2017, reported results in [4]) and our work on analysing program coherence and importance and connections between courses and concepts in [1-3].

[1] E. Fjällström, C. Forsberg, F. Trulsson, S. Knorn, K. Staffas, D. Varagnolo and T. Wrigstad, “Courses-Concepts-Graphs as a Tool to Measure the Importance of Concepts in University Programmes”, accepted at European Control Conf., 2019.

[2] S. Knorn, D. Varagnolo, K. Staffas, T. Wrigstad and E. Fjällström, „Quantitative analysis of curricula coherence using directed graphs“, submitted to IFAC Advances in Control Education Symposium, 2019.

[3] D. Varagnolo, S. Knorn, K. Staffas, E. Fjällström and T. Wrigstad, „Graph-theoretic approaches and tools for quantitatively assessing curricula coherence“, submitted to European Journal of Engineering Education, 2019.

[4] E. Fjällström, S. Knorn, K. Staffas and D. Varagnolo, „Developing Concept Inventory Tests for Electrical Engineering (CITE): extractable information, early results, and learned lessons“, 12th UKACC Intern. Conf. on Control, 2018. 7.

2.3 Personnel

The project was conducted jointly at UU and NTNU and was led at UU by André Teixeira, Steffi Knorn and Kjell Staffas and at NTNU by Damiano Varagnolo. The project also involved the program boards and program managers for Electrical Engineering at UU and NTNU, teachers in the programs, and student representatives.

3 Implementation and method

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

Part 1: Develop methods and tools to describe, analyse and visualise interconnections between FCPs and their taxonomy levels and connections to PLOs as knowledge ladders in general.

Part 2: Develop methods on how information can be extracted from different sources such as course goals, teaching material, exams, TLAs and expert opinion (e.g. through interviewing teachers) to describe the interconnections between FCPs and their taxonomy levels and the overall PLOs.

Part 3: Test the developed methods by investigating knowledge ladders for selected key components of the EI program, that should ideally span over significant parts of the program, considering both a bottom-up approach (starting from ILOs from early courses and prerequisites from high school) and a top-down approach (starting from PLOs).

Hence, Part 1 created a general method to describe the system and establishes a notation and structure of knowledge ladders, that should be suitable for analysing and understanding how FCPs build up and depend on each other and finally connect to PLOs. In Part 2, we investigated methods on how information for a specific program can be extracted from existing material and which advantages and limitations each of the possible information source has. Finally, Part 3 connected and validates the work in Parts 1 and 2 as it aims at testing and evaluating the methods to ensure that they are striking a good balance between being easy to implement with few resources and being comprehensive and suitable to extract valuable information and analysis.

4 Results

4.1 Establishing a joint language / notation and structure of FCPs

Due to our previous work, see for example the previous PUMA-project "CITE", work within the field of engineering pedagogy, and a work with NTNU and other international partners in a larger Erasmus+ project, we were already aware of the immense difficulty to agree on a common language between teachers, students and boards. For instance, even though basic concepts from mathematics and electrical engineering basics are often referred to and built upon in more advanced classes, the notation and description varied a lot. Hence, in order to combine information about taught FCPs from several courses in order to then analyse their coherence and interplay it became clear that a common notion of what is called what etc was essential.

Our first attempts to establish a database of taught or included FCPs in a democratic and crowd-sourcing style mostly failed due to the complexity of the task combined with the lack of time most teachers face. Also, in order to be able to transfer results between universities, it is not necessary that teachers at an institution agree on or develop their own catalogue of FCPs - specially when teaching well established subjects and programs. Hence, we concluded that it would be more efficient if a joint catalogue of FCPs was developed by experts in the field respecting the following constraints and conditions

- notions of FCPs must include synonyms[1], common abbreviations[2] and plural as well as singular terms where applicable in order to include everybody's preferred description/notation without the need to agree on a single person's version;
- must structure the FCPs such that teachers may easily find FCPs in the list without having to guess / look for items manually; and
- must include a hierarchy to allow for more coarse or more finely detailed information[3]

Such structured lists were then developed for several areas of mathematics (including for example linear algebra) as well as the field of systems and control in order to test and evaluate the feasibility of the method.

In order to handle the information, it became clear that an IT-tool had to be developed in order to handle the data in an efficient and effective manner. Hence, a web-based tool was developed. See more information below.

4.2 Establishing a joint language to describe difficulty and mastery level for FCPs

It also became apparent that teachers in engineering disciplines face difficulties when describing the expected level of mastery for the required knowledge in order to take a course (prerequisites) or the required level to pass a course or course goal in terms of taxonomy. Our research in this

[1] Such as "state observer" and "Luenberger observer".

[2] Such as, e.g., "ODE" for Ordinary Differential Equation".

[3] For example include "Operational amplifier circuits" as well as "Inverting amplifier", "Noninverting amplifier", etc as subcategories of "Operational amplifier circuits".

area showed that this was due to several problems with existing taxonomies that are often not directly suitable for engineering or STEM disciplines. For instance, mixing different kinds of mastery was deemed a problem: In engineering there is often a clear distinction between being able to apply or use a FCPs and understanding or being able to explain it. Being able to do one does not necessarily imply being able to do the other. Also, the levels of the taxonomy should be easy to identify and quick to understand such that teachers may use it without much time to learn or get used to it.

For this, a two dimensional taxonomy was developed with three levels on each axis. Whereas the first axis describes the ability to use or apply FCPs, the second describes the levels of difficulty to reason, reflect and explain aspects of the FCPs. The taxonomy was tested by several volunteering teachers at UU, NTNU and other participating universities.

It also became clear that teachers often have a hard time to describe the required knowledge for their course or the expected knowledge level of students passing their course in an abstract manner. However, they usually were able to readily identify which associated exam questions students should be able to correctly solve before, during or after their course. Hence, instead of describing the taxonomy levels of their course in an abstract setting, they were instead asked to identify the taxonomy level of (their) exam questions. This also served the most welcome bi-effect that teachers did not identify the taxonomy level or their wishful thinking of what students might achieve but rather what was really required for passing the actual course. Hence, the identified information was deemed more realistically reflecting the actual level of learning in the course.

4.3 Processing the course information and their interconnections

We identified several forms in which two FCPs A and B may be related to each other:

- A is required to learn B
- A is useful to learn B
- A is equivalent to B
- A is included in B

Whereas the last two relationships may be tacked by including this information in the design of the FCPs-repertoire of the discipline, the first two (necessity and usefulness) indeed describe parts of learning paths or learning ladders. Hence, based on our own understanding and feedback from students, we established a graph-like representation of those relations: "A being required to learn B" was hence visualised by a solid arrow from A to B whereas "being useful to learn" would result in a dashed arrow.

Several teachers at UU, NTNU and other partner universities then collected information in this form for their courses, which was a mostly smooth process.

4.4 Allowing student interaction with the database

In order to allow students to benefit from the collected information it became clear that the mere information what is required to take and to pass a course is helpful but rather abstract to students. This is due to (1) students maybe not knowing the terms used to describe the FCPs for courses' prerequisites or learning goals and (2) students often being too optimistic about their achieved learning goals so far.

Hence, in order to give them a more realistic picture and allow for some relevant and realistic self-assessment of associated FCPs, we integrated the option to see and answer sample exam / exercise questions (mostly multiple choice) or specific FCPs, which are then automatically graded in order to allow for direct individual feedback. This way, students can in fact get a much better overview if they are in fact mastering the required FCPs for a course (prerequisites). Also, by integrating typical exam questions students may in fact get feedback before taking the actual exam, which motives them further to interact with the developed tool and hence increases their overal engagement in the project, including the reflection of where they stand, how knowledge build up and what is included in specific courses.

4.5 Developed IT-tool

As mentioned above, the developed methods and required data and information required automatic handling and processing. Hence, a web-based tool was developed, that included the following features

- teachers can upload information about their course's CFPs, including their connections and associated taxonomy levels in a structured fashion
- teachers can upload exam questions linked to specific CFPs and specify also the taxonomy level of the question using the developed two-dimensional taxonomy
- students and teachers can see a graphical representation of how CFPs of a specific course or several courses of a program are related (relating the CFPs with arrows according to "being necessary to learn" and "being useful to learn")
- students may answer questions on chosen FCPs and get direct feedback on them as well as seeing their learning graphically illustrated in the graph

5 Conclusions and future plans

The developed tools and results are in fact promising. Feedback from students has been very positiv and encouraging. Of course, as usual, one underestimates the required engagement of the teachers at the same time as overestimating their willingness to contribute and time. However, that said, most teachers also reflected very positively on the fact that collecting the required information on their courses is an investment into the quality of their teaching, simplifying and supporting their communication with the students and a valuable opportunity to reflect about their teaching. Also, the fact that the information often changes only somewhat between years means that efforts will be much less when using the tools for several years.

Teachers and administrators also brought up the positive fact that being to able to establish a common language to describe the courses' contents, their interconnection and associated knowledge levels allows for a better, more transparent and hence simplified comparison of courses, which may be a valuable tool to use to decide which courses students may swap or take in other institutions (e.g. when studying a semester abroad).

In the future we will investigate these issues further as well as continue to test the developed software platform to see if it is technically ready for larger amounts of users as well as handling an ever growing amount of data in the associated database.

6 Reporting of the results

We have used several opportunities to report our work, which include:

- A. M. H. Teixeira, A. O. P. D. C. Guerra, S. Knorn, K. Staffas, D. Varagnolo. "Computer-aided curriculum analysis and design: existing challenges and open research directions". 2020 IEEE Frontiers in Education Conference (FIE), Uppsala, Sweden, 2020.
- K. Staffas, S. Knorn, A. O. P. D. C. Guerra, D. Varagnolo, A. M. H. Teixeira. "Using different taxonomies to formulate learning outcomes to innovate engineering curriculum towards PBL: perspectives from engineering educators". In 8th International Research Symposium on PBL, Aalborg, Denmark, 2020.
- E. Fjällström, K. Atta, S. Knorn, F. Sandin, G. Sas, K. Staffas, A. M. H. Teixeira, and D. Varagnolo. "Creating a quantitative basis for course and program development in higher education - a report from field tests". In Proc. 7th Development Conf. for Swedish Engineering Education, Luleå, Sweden, 2019.

Also, the results were further spread to partner universities through our collaborations within a related Erasmus+ project with

- Free University of Brussels
- Padua University
- Otto-von-Guericke University Magdeburg