Using data mining to understand how technology is expressed in curriculums to mediate learning outcomes

Christian Wahl

IT Study Programs, University College of Northern Denmark, chwa@ucn.dk

Peter Nørkjær Gade

Department of Architectural Technology and Construction Management, University College of Northern Denmark, pega@ucn.dk

Abstract

The role of technology in education increases with the increasing need for students to master technology in their practice. However, mastering technology in modern practice has become increasingly complex and requires a deeper understanding of the technologies—technologies hold premises in terms of how they limit and enable actions. While correct use can improve practice, wrong use can harm and lay waste to resources and job satisfaction. Ensuring that students can manage this complexity requires that technology is actively reflected in realistic settings. However, how do the curriculums that steer education reflect the role of technology, and do the curriculums steer the learning of technology in an advantageous direction? In this study we investigate curriculums across educations to explore how technology is expressed. This exploration will be used to discuss the role of technology in education, how it is expressed in curriculums documents, and its potential advantages and problems. The exploration is done using text mining to identify and extract specific features of the natural language of the curriculums. The features extracted will be used to highlight specific patterns related to the use of technology in education. The contribution of this paper is twofold. Firstly, it provides a method for data mining to identify patterns of technological use in education, manifested in curriculums. Secondly, it shows how technology is viewed in education.

Keywords

data mining, learning outcome, SOLO taxonomy, technology in education, curriculum

Introduction

The presence of technology is becoming more relevant with the advent of increasing efficiency and understanding in professional practice. Architects need to extend how they design their buildings, and nurses want to mediate better treatment. A professional practitioner must master technology and understand how to reflect and use technology (Schön, 1983). In education, we need to accommodate technology so that future practitioners can mediate their practice and include the educational considerations of using technology described by learning outcomes in the curriculums.

Technology has many roles in connection to education and teaching. First of all, educational technologies are used as a medium for communication. The building block for these technologies is language. In this sense, language itself is a technology supported by artifacts like blackboards, computers, pens, and paper used in the classroom. These technologies are combined with more process-oriented technologies like the teaching methods applied by the teacher. Each technology facilitates the process of learning by enabling communication between students and teachers. Technology can also be the object or the theme in teaching and learning. Students can learn about the technologies they are surrounded by and learn about the technologies a profession uses. We use technologies all the time, and often we need to learn how to make use of and understand them. As an example, not only do students use social media, but they need to know how social media works. Moreover, not everyone will be a cook, auto mechanic, or computer scientist, but students still need to learn about the technologies used in their everyday lives. In some cases, students need to learn specific technologies. If they are students in a particular discipline, they need to know about the technologies used by that profession. These are the technologies that we will focus on in this article.

Technology in education

The role of technology in society is becoming increasingly important as a solution to many societal challenges. Technology is both a tremendous societal benefit and, in many cases, introduces unforeseen challenges and problems that need to be accommodated. Technology does not determine innovation but relies on human agents to explore its use through play and experimentation with associated perceptions of its possibilities. Therefore, technology not only constitutes the tools that humans use to solve problems but can be viewed as cultural artifacts that embed values, intentions, and world views that implicitly contain particular rationalities (the way artifacts are designed to work) that our society needs to comprehend in order to use the technology properly (Hasse and Storgaard Brok, 2015).

In education, students need to understand technology as cultural artifacts and interpret it in their situated practice for its purpose. For example, Danish students in building design often use technologies developed in a North American context. Therefore, to use the technology properly, the students need to understand the cultural influence under which the technology was developed and re-interpret the technology for the students' situated professional practice in Denmark. Technology as a cultural artifact contains values in respect of what a building design should contain and how it should be presented that might not suit the Danish building design culture, and therefore needs to be adapted. The educators should be aware of such cultural aspects and facilitate such understanding and adaption to integrate the technology properly in the learning environment.

Wartofsky (1979) was a proponent of looking at artifacts as cultural tools representing the artifacts themselves and cultural meaning across contexts. Wartofsky differentiated between three different categories of artifact, expressing their ability to mediate cultural history and meaning. Primary artifacts are items such as axes, pens, or cars. Secondary artifacts would be manuals for driving a car, proper use of axes, or reusing pens. Tertiary artifacts are often considered works of art that "constitute a 'world' (or 'worlds') of imaginative praxis" (Wartofsky, 1979, p. 207). In other words, tertiary artifacts allow human imagination to mediate their actions in domains other than the artifact's intended.

This view resembles how the later learning theory of observed learning outcomes (SOLO) taxonomy views the highest level of learning, extended abstract, in which the student can extend their knowledge about a field to new domains. Examples of these tertiary artifacts have been differentiated between where-from and where-to. The where-from consists of an amalgam of historical contexts of the artifacts used—for example, the reasons why electrical panels look like they do. Where-to are visions-of-the-future artifacts, where a piece of artwork is used to convey a vision of an organization's future ambitions, like a car designer company that wants to direct its car designs toward resemblance of a jaguar, both physically and culturally (embedding speed, power, and exoticism).

These different levels signify the potential affordances that technological artifacts contain. Affordance is the latent potential of technology to mediate human action. When teachers' and students' bodies and minds are intertwined, their use of technology fulfills its promise. Yet, this promise is restricted by the teachers' and students' user experience, which, when lacking, restricts students' ability to imagine the technology's use. It is therefore essential to let the students learn from teachers and mentors with experience of using the technology and to install more features that allow the students to extend the technology's use beyond what was intended. With technology, new affordances appear, especially regarding ICT. There is a need to promote learning about meta-knowledge—i.e., where to find and valuate knowledge—which will support students' ability to solve problems in an ever-changing world (Somekh, 2007).

Technology in curriculums and relationship with learning outcomes

The role of technology in education is manifested in the main steering document for education, the curriculum. Curriculums are official documents agreed upon and used across institutions in Denmark. It is here that educators interpret the role of technology according to the learning outcomes defined and give direction to the teachers work and secure an aligned learning environment. Accommodation of the learning outcomes for the technology must be aligned with the other learning outcomes and the concrete context of the students; it is therefore subject to the individual teacher's interpretation. These interpretations are then based on the teacher's own perceptions and ideas about teaching and the technologies introduced to the students.

Curriculums are fundamental to educational programs in terms of manifesting the learning outcomes and helping teachers guide the education of the students. Curriculums must express the objectives for each learning activity and the evaluation of these activities. Typically, curriculums are expressed by high-level and abstract verbs that signal students' knowledge, skills, and competencies. Teaching and learning can be perceived as a whole system connected from the concrete classroom to the department and institutional levels of the organization. It has been argued that a discrepancy between the learning outcomes and what is actually done at the different levels constitutes a poor learning and teaching system. Biggs et al. (2013) argued that to ensure an aligned learning environment, there must be defined desired learning outcomes, related activities that lead to these outcomes, proper matching of what the students are learning, and a final grade.

Learning about and with technology will be an increasingly crucial aspect of education. How education frames the role of technology for students impacts how they can act with technology in their future professions. This article will explore how learning outcomes concerning technology in education are manifested as cultural artifacts in curriculums to identify specific patterns in relation to the SOLO taxonomy. Identifying these patterns will highlight the relationship between technology, education, and the learning outcomes described in curriculums.

Methodology

In order to explore the connection between technology and learning outcomes in curriculums, we base this investigation on a concrete case. The case used is the University College of Northern Denmark (UCN), an educational institution with 35 educational programs based on two educational levels: academic professional (AP) and Bachelor's degree.

Data mining

Data mining is an umbrella concept that refers to various techniques used to analyze large quantities of data. This can be done analogically, but today, it is often done digitally. Analyzing a large quantity of data is about identifying and exploring interesting patterns. Data mining is often used to analyze documents containing rich semantic and syntactic structures in explicit and implicit content from which patterns can emerge. It requires an understanding of the natural language and the structure of the documents—for example, how natural language expresses the pedagogical applications of technology in the curriculum.

The method can broadly be divided into pre-processing, core mining operations, and presentation (Feldman and Sanger, 2006). Throughout the analysis, we used the programming language R and related packages. Firstly, documents had to be collected and cleaned. This is a part of the pre-processing. Two aspects of data mining are considered critical: scrubbing and normalizing data. Scrubbing data and normalizing the data comprise a process of transforming unstructured data that need to be removed or fixed for the patterns to emerge. We configured a web crawler (Rcrawler) to search the UCN website for PDF files from the different educational programs to collect all the curriculum documents. In scraping the website for curriculum documents, we inspected some of the HTML pages for the structure of these pages. All links to the curriculum documents appeared in reverse chronological order, meaning that the newest revisions were at the top. Most educational programs had two curriculum documents, one for national and one for institutional regulations. We therefore decided to pick the top two documents from every page, except for pages with only one link.

The text from the PDF files was extracted using the package pdftools. A common challenge in these documents is that there are many headers and lists where punctuation is occasionally omitted. It thereby becomes unclear when a sentence ends, and often what is considered a sentence does not convey meaning in itself. In a couple of cases, the document's text was rendered as images, so we had to undertake optical character recognition (OCR) to extract the text using Tesseract. Finally, basic metadata were collected about the relationships between the documents and the educational programs. As part of the pre-processing, the extracted text was cleaned by removing sentences shorter than four words, converting all characters to lower case, removing punctuation, annotating, and stemming words. This process gave us a collection of structured data and metadata for the analysis.

The core mining operations are the techniques involved in doing the analysis itself. Two main techniques are in use. One is finding the frequency of the term ‘technology’ in the texts. The other is finding the relationship between the educational program and the taxonomical level across sentences where the term ‘technology’ is present.

Using SOLO taxonomy to identify verbs and their relationship with technology

The SOLO taxonomy can help classify learning outcomes regarding complexity and quality. The SOLO taxonomy rates student activities in five categories, from pre-structural, to uni-structural, multi-structural, rational, and extended abstract, each specifying characteristics of students' understanding (Biggs and Tang, 2011). These characteristics are expressed as verbs. In a uni-structural understanding of a field, the student can identify and name certain aspects of a knowledge domain and express certain procedures. For example, in the construction industry, one can identify and name materials and express simple procedures for using these materials. In the extended abstract, the student can generalize knowledge about, for example, building materials, apply that to different cases, and reflect upon potential challenges. See Figure 1.

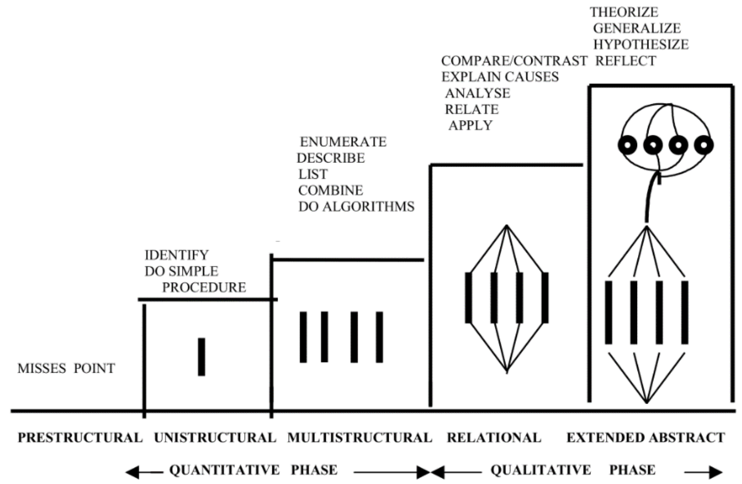

Figure 1. A hierarchy of verbs that may be used to form curriculum objectives (Biggs and Tang, 2011, p. 91)

Regarding the case of UCN, learning outcomes are divided into three classes according to the taxonomic level in the curriculums. These classes are knowledge, skills, and competencies. For each element/module/course in a program, the learning outcomes are structured according to these classes. We have not attempted to capture this structure in the following analysis because different documents have different layouts. Therefore, we treat every sentence in the document as an independent unit. For each unit (sentence), we identify the term ‘technology’ in connection to the verbs used. Using the SOLO taxonomy, we then identify verbs in curriculums that signify different levels of competence. These levels can be used to signify how learning outcomes are expressed in curriculums.

In the last phase of the data mining process, we present data in three different ways. The frequency of the term ‘technology’ can tell us where the term is most often used. We display the frequency of the term across sentences in a graph for each educational program. Secondly, we summarize verbs in connection to the term ‘technology’, first by their frequency and then by their relationship to the SOLO taxonomy. We display this in tables. Finally, using the package igraph, we display the relationship between the two concepts—the educational program and the SOLO taxonomy—in a graph. This graph is based on the relationships between the verbs that are categorized using the SOLO taxonomy and the term ‘technology’. After presenting the data, we use selected excerpts from the texts to exemplify our findings.

Results

In this section we present how the learning outcomes in relation to technology in the curriculums of the educational programs are manifested as cultural artefacts. For this purpose, we use UCN’s curriculums with our above presented method. Using the SOLO taxonomy and data mining allows us to identify specific patterns that can highlight the relationship between the role of technology and education. These results are presented in two sub-sections, the first, how often the term ‘technology’ occurs in each of the curriculums, and secondly, the relationship between the verbs related to the SOLO taxonomy and the term ‘technology’.

Occurrences of the term ‘technology’

The most basic analysis is the collection and summarization of all the relevant sentences in the documents. Here, we are looking for sentences that contain the term ‘technology’. In Danish, words are often compound words, which means that the word ‘technology’ can appear in combination with other words. The term ‘web technology’ is an example: in Danish, this would be ‘webteknologi’. These words are also included in the analysis.

We calculated what percentage of the sentences contained the word ‘technology’ for each curriculum. As shown in Figure 2, not surprisingly, some of the more technical programs are at the top: here we can list Product Development and Technical Integration, Multimedia Design, and IT Technology.

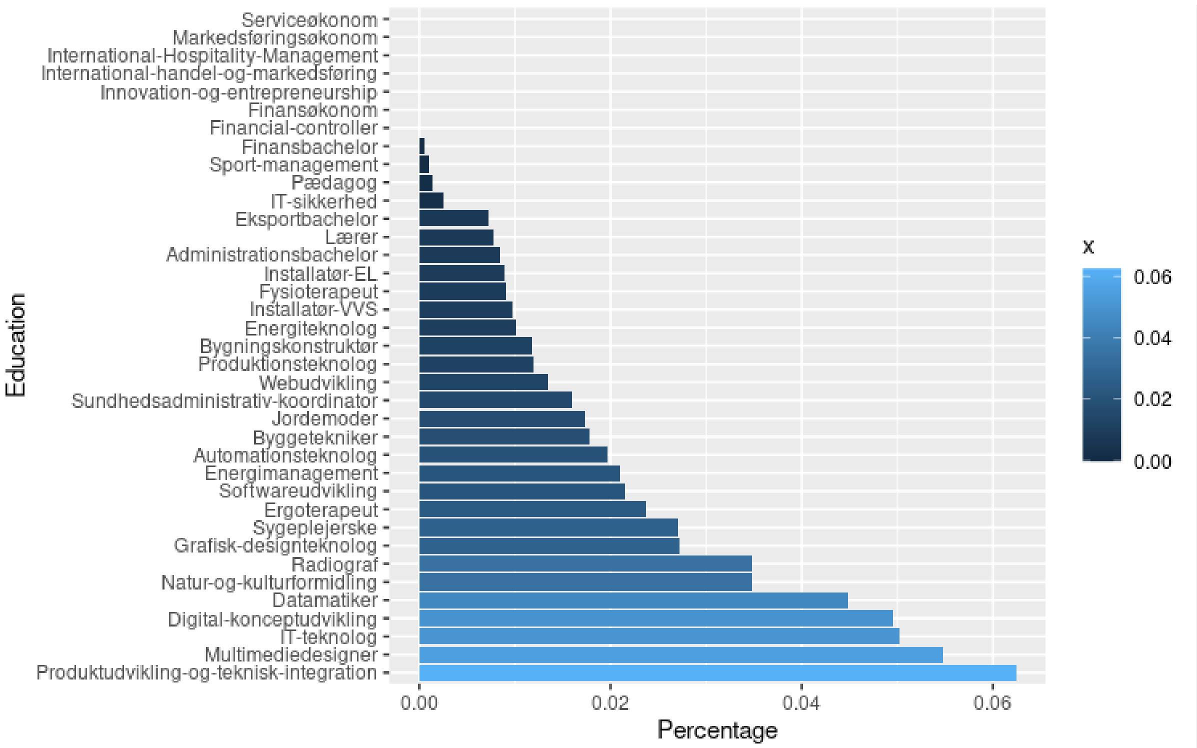

Figure 2. Frequency of the term ‘technology’ across 37 different curriculums

Looking more closely at the curriculum for product development and technical integration, we find that students should have "knowledge of theory and practice within product development and technical integration, based on an understanding of technology that includes the elements technology, knowledge, organization and product." In the curriculum for multimedia design, we find something similar. One of the program elements is called “User interface design and technology”, and one of the learning outcomes for this element is that the students learn skills in "applying key technologies for exchanging and presenting complex data sets in digital user interfaces".

These two are examples of how technology is expressed in the more of the technical programs. In the first example, students should have a specific understanding of technology that can inform their knowledge about theory and practice in the profession. In the second example, students should learn skills using technologies.

More surprisingly, some of the health-related educations also appear near the top in Figure 2. One is education in radiography, which is maybe not that surprising in that it involves using a lot of equipment. The following is an example of one of the learning outcomes: "... apply, justify, and evaluate radiographic techniques and methods in the choice of modality in connection with the planning, implementation, and evaluation of MRI, X-ray, and CT examinations and assessing the possibilities and limitations concerning optimal use of the technologies." This is a lot to take in, but basically, students should apply, justify and evaluate technologies used in radiography. Another health-related education is nursing education. A learning outcome for the students in nursing education is that they should be able to "apply and reflect on technologies in the application and development of care, nursing, and treatment." For both health-related programs, not only does technology have a function within the profession, but the students should learn to reflect upon and evaluate the use of technologies.

The relationship between the verbs related to the SOLO taxonomy and the term technology

The results of the data mining showed that 71 verbs associated with the term ‘technology’ were identified across all the curriculums. As shown in Table 1, the most relevant was the verb use (Biggs and Tang, 2011).

Table 1. List of top 15 verbs

Verb stem (Danish)	Verb (English)	SOLO level	Number of references
anv	use	3	51
reflek	reflect	4	35
vurd	access	3	21
forstå	understand	1	14
påtag	undertake	3	13
anvend	use	3	11
arbejd	work	3	11
begrund	reason	3	9
hånd	handle	3	8
kombin	combine	4	8
analys	analyze	3	7
inddrag	include	1	7
indgå	be part of	3	7
udvikl	develop	3	7
beskriv	describe	1	5

Each verb was manually categorized based on the SOLO taxonomy. This procedure, of course, relied on our judgment and was challenging to apply because not all learning outcomes are expressed as intended learning outcomes (ILO) (Biggs et al., 2013). The second column in Table 1 represents all the verbs translated to English. The mapping of the verb to the SOLO taxonomy is found in the third column and the frequency in the fourth column.

Table 2. The relationship between verbs and technology following the SOLO taxonomy’s levels

Level	Title	Number of references
0	Pre-structural	0
1	Uni-structural	4
2	Multi-structural	6

3	Relational	48
4	Extended abstract	13

In Table 2, the data indicate that the taxonomy level referred to most is the relational level. The first level, the level named uni-structural, is not referred to that often. There could be several reasons for this. One reason could be that the general term ‘technology’ is not mentioned under the subsections concerning knowledge of the taxonomical class. One of the features of SOLO is that knowledge underlies all levels, but in general, verbs like ‘memorize’, ‘identify’, or ‘recite’ are too basic when it comes to the formulations used in the learning outcomes. As mentioned above, we cannot know this because sentences are independent units in the analysis. Another reason could be that technology is always connected to a verb in one of the other levels when mentioned. For example, objectives do not state that students should know specific facts, but instead that they should be able to access something or justify choices, which implies that they should also know something about the subject area. An example could be nursing education, where one of the learning outcomes under the subsection ‘Knowledge’ states: "[The student can] reflect on the profession's use of technology in care, treatment, and quality assurance." In our analysis, this sentence will count as an observation with a connection between ‘reflect’ and ‘technology’. So, firstly, the sentence will count in the extended abstract level. Secondly, it is difficult to pinpoint precisely what knowledge the student should have in this case, but students should probably know something about the technology in this context in order to reflect.

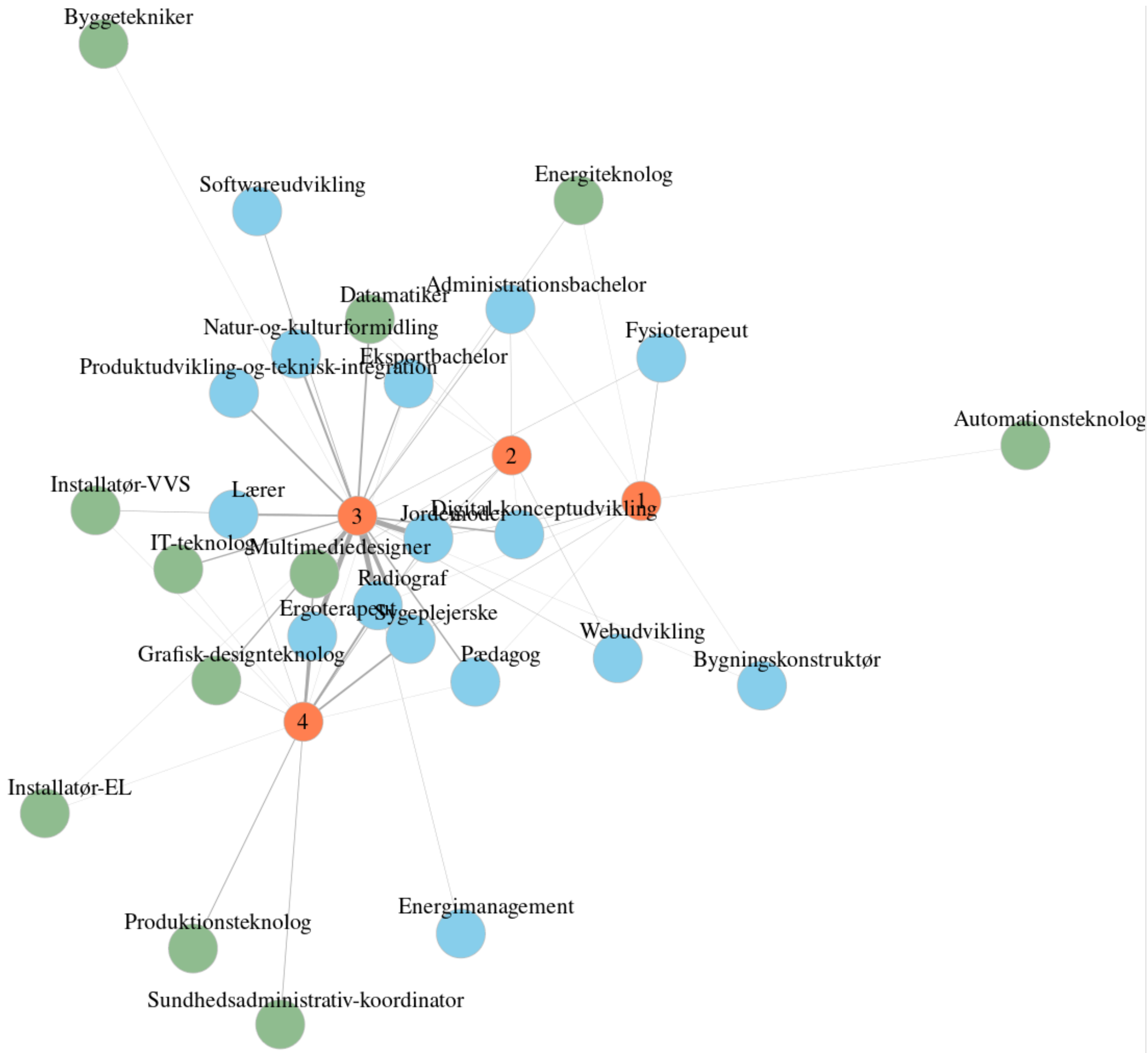

Figure 3. The relationship between educational programs and the SOLO taxonomic levels

Figure 3 illustrates the relationship between educational programs (or the curriculums) and the levels in the SOLO taxonomy. Two different academic degrees are represented in the figure. The green represents academy profession (AP) degrees and the blue represents Bachelor's degree programs. The weight of the edge (the lines) is an expression of the number of observations. The larger the weight, the closer the education and the level vertexes are. Across all curriculums, there are 315 observations. One edge in Figure 3 is an aggregation of one or more observations where the verb and the term ‘technology’ are found in the same sentence. It is important to stress that Figure 3 is not a general expression of how the different curriculums use verbs or taxonomies in learning outcomes. The data collected are only concerned with those sentences that carry the term ‘technology’.

Interestingly, levels 2, 3, and 4 are the levels that have the most relationships, even though Table 2 shows that level 3 is the most prominent. This is because a lot of the relationships to level 3 are aggregated into one, and at the same time, more educational programs refer to levels 2 and 4, but not that often. This shows us that the relational level is dominant, but equally that the learning outcomes that include the term ‘technology’ address the multi structural and extended abstract levels. An example of a learning outcome on the relational level is the syllabus in web development: "[Students can] implement a solution with the chosen technologies." The students should be able to apply what they have learned using technologies. At the same time, they should be capable of choosing between different technologies, which suggests that this objective also requires the students to analyze the relationship between the technologies and the relationship between the technologies and the context.

An example from the occupational therapy curriculum is: "The student can discuss and analyze technology and the therapeutic potential of the technology". Not only should the students have knowledge about and skills in using technology: it is also essential that they can discuss and analyze how technology is part of their profession. Even though this learning outcome seems to be on a higher level than the example from the web development curriculum, in terms of the SOLO taxonomy, we are still on the relational level. Another example is from the occupational therapy curriculum: "The student can reflect on the profession's use of information and communication technology". Not only should the students be capable of discussing and analyzing the use of technology, but they should also be able to reflect on the use of technology in the profession. In the context of the SOLO taxonomy, this objective fits into the extended abstract level.

The weight of the edges in Figure 3 suggests that some of the educational programs show a more frequent relationship between our list of verbs and the term ‘technology’. As the only AP degree, multimedia design is placed close to and between the relational and extended abstract levels in Figure 3. A closer look at the curriculum reveals that we have a total of 30 references. Students should, of course, be able to select and use technologies—skills that we have placed on the relational level. On the extended abstract level, we have placed verbs like ‘designing’, ‘programming’, and ‘combining’, which are crucial skills for a multimedia designer. This is similar to programs that focus on reflection in relation to technology, like the occupational therapy program mentioned above.

An example of a program that directs the attention more to the cultural use of technology is the Bachelor’s degree in Natural and Cultural Heritage Management. The program is in the upper quadrant in Figure 3, with frequent usage of the term ‘technology’ in the curriculum. This is interesting in itself. The students' skills in using technology and digital technology are essential, as shown in this example from one of the main subjects in entrepreneurship: "The student can use and justify the choice of digital technology in a practical context." The use of technology in relation to the educational programs in the field of the experience industry/economy shows another side of technology in addition to the more technical educational programs where the focus is more on development.

Discussion and Conclusion

Using the theories of Wartofsky (1979) on technology as culturally mediating artifacts, learning outcomes, and the SOLO taxonomy (Biggs and Tang, 2011), we enabled a structured exploration of the curriculums using the data mining methodology (Feldman and Sanger, 2006). Using this methodological framework, we were able to discover interesting patterns in how different educational programs have interpreted the role of technology. The analysis resulted in various competencies concerning technology's role in education based on the level and type of education.

Differences between the role of technology in the educational programs

Our results show that different educational programs relate the term ‘technology’ to various verbs in reference to the skills and competencies related to technology spread over both the academic level and subject area. Generally speaking, the use of the term ‘technology’ falls into three categories: understanding technology, using or applying technology, and reflecting on the use of technology in the context of the profession.

A pattern in our results shows that, in relation to the SOLO taxonomy, educational programs that heavily rely on technology as a part of the profession do not refer to technology as an abstract phenomenon in their curriculums. Here, the technology is embedded in the profession and therefore taken as given. For example, the curriculum for theBachelor's in architectural technology and construction management only has relations between ‘technology’ and the taxonomical level 1 and level 3. This shows that there are no learning outcomes in the curriculum to reach the extended abstract level where competencies are used to generalize or reflect—i.e., the profession does not deal with the abstract notion of technologies per se, but instead with concrete tools like building information modeling (BIM) or digital simulation of statics. Students are thereby encouraged to use concrete tools like BIM to solve concrete problems. Here, the technology does not act beyond its primary aim (primary artifact) and its use is not encouraged outside specific cases specified in the curriculum. This shows a dichotomy between the overall objective that students should learn to reflect on technology and what the curriculum expresses, a dichotomy that can lead to misalignment and restrict students’ ability to act with technology in their educational or specific application context.

In contrast, health-based education in professions like nursing, midwifery, and occupational therapy is very high in the SOLO taxonomy and is very explicit when expressing the connection between the profession and the use of technology. While one would not typically consider these educational programs to be technology-centric, the curriculums reflect learning outcomes that strive to contend with technology in the profession more abstractly, as seen in the results section. This shows how students are encouraged to, for example, analyze using technology, and thus signals a tertiary approach to the technological artifacts. Here, reflecting with the use of technology implies an in-depth understanding of the technology's culture in the education. The history of the technology how was it devised, who helped develop it, and how it can be used form the foundations of analyzing technology within the profession. Tertiary artifacts define students’ professional direction to enable reflection and allow them to imagine alternative activities using the technology (Engestrom, 2007).

Differences between educational levels and the SOLO taxonomy

In Table 2, it is apparent that level 3 (relational) is the most commonly mentioned, with two-thirds of all the references. This fits well with the overall Framework for Qualifications (the Danish version distinguishes between AP and Bachelor's degrees). Here we refer to one of the bullets: in the AP degree, students should understand and use theory and methods in their praxis, whereas students should understand and reflect on theory, methods, and praxis in the Bachelor's degree (Uddannelses-og Forskningsministeriet, 2008). In both degrees, students should, of course, use and understand theory and methods, which could be the reason for the many references to level 3. However, even though there is a clear distinction between the two educational degrees, it is not clear from Figure 3 that level 4 in the SOLO taxonomy, in theory, should relate more to the Bachelor’s programs. The relationships between AP degree programs (green vertexes) and the level vertexes are similar to the relations between Bachelor's degree programs (blue vertexes) and the level vertexes. On the one hand, this is surprising. However, the nuance between the two educational degrees in the Framework for Qualifications can be hard to follow. Therefore, it can be hard to formulate the often-abstract learning outcome in the curriculum.

Limitations of using data mining to explore the role of learning outcomes in curriculums

We only searched for the term ‘technology’ in our analysis, and there could be many synonyms for the term that we overlooked. We search for an abstract concept where the curriculums maybe use more concrete terms. An example from the education of financial controllers could be: "... use methods and tools in financial management systems and processes." Here, it states that students should be able to use ‘tools’ within the context of the profession. Tools, systems, and processes are all considered forms of technology. Often, sentences are constructed in a way that makes it unclear which verbs are related to the term ‘technology’. We picked sentences (or fragments of sentences) where the verb preceded the term ‘technology’, but the appropriate verb might be placed later in the sentence. In these situations, the relationship between the verb and the term is missing in the analysis. An example of a sentence from the educational program for digital concept development is: "... understanding the interplay between human, business, society and digital technology based on relevant theories, methods, and analyses." In our analysis, this ended up as a relationship between ‘understand’ and ‘technology’. However, at the end of the sentence, we can see that the understanding should be based on analysis. So, this learning outcome would require the students not only to understand the technology but to analyze it.

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