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Taxonomic Competence Modelling – Observations from a Hands-on Study and Implications for Modelling Strategies

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Abstract: Following previous postulations for a global, integrated competence management system, this paper belatedly publishes and evaluates reflections from a 2014 study of taxonomic competence modelling. Mechanical engineering master students explore modelling their recent bachelor program as a study project. Following a systematic methodology with typical elements of a competence syntax, they encounter significant problems of inconsistency in all aspects of their data. Their reflections showcase that taxonomies are not suitable for a decentrally maintained competence model, competence levels and categories should be avoided from the core structure of a model, and both key aspects of a syntax should be kept flexible in a semantic network.

Keywords: integrative competence management, competence modelling, representation syntax, taxonomy, mechanical engineering.

1 Introduction

In previous publications, the strategic need was presented to define and establish a global, decentralized digital infrastructure for an integrative competence management system ([Da06], [DSR16], [Da19]), allowing participative management of life-long learning from individual personal, educational, and organizational perspectives. The underlying functional framework features a distributed, pervasive, and digitally operable competence representation model as a key element. In [Da19], the author derived guidelines for the core model's type and structure from an analysis of functional requirements.

As a follow-up in this workshop, hands-on experiences from modelling competencies in a technology-based domain are presented and evaluated as a set of two papers: The first (this) paper portrays more in detail the practical problems of a taxonomic modelling approach, and why this is unapt for decentralized competence management. The second paper [Da20] explores the process and challenges of a semantic approach, including the search for semantic tools for non-IT-experts to model domains as ontologies or graphs.

Although modelling of taxonomic domain competencies is not novel for itself (e.g. [EC20]), the specific exploration perspective of decentralized competence modelling can be considered – as outlined in [Da19] – as highly relevant for understanding the challenges

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in this process.

Based on [Da19], *competence* will herein refer to *a semantic network of representations of a perceived reality, dispositioning its owner to cause an effect or induce a change within himself, or someone / something without himself.*

2 Methodology

In [Da19], the author analyzed the logic problems of taxonomies and other hierarchic classification approaches for a universal, distributed, context-sensitive competence representation model. The study referenced in this paper pre-dates this theoretic analysis (and contributed to it), and illustrates in more detail the practical challenges that arise even in a highly homogenous context by the example of a hands-on study.

The goal of the study was to explore the modelling process with open outcome and to understand implications for modelling strategies. Therefore, this paper compiles and evaluates qualitative, subjective testimonies and emerging reflections for what worked and what did not.

The study was conducted in an interdisciplinary project-based course in a master program for mechanical engineering at the Hochschule für Technik und Wirtschaft Berlin – University of Applied Sciences. Criterium for participation was only to opt for the specific, untypical project task over other more typical engineering tasks.

In April 2014, a team of five master students volunteered for a study to map competencies of courses in the bachelor program of mechanical engineering. They had completed the bachelor program only one year before, so they had experienced and could still recall the learning results of courses beyond course description. The team consisted of a group that had already worked together regularly in their bachelor program.

The project task was to research and develop an approach to map learning outcomes to program courses, to apply this independently from each other to at least one self-selected course per participant, and evaluate comparability of the resulting competence syntax. Participants were also asked to reflect and document their own modelling experiences. The observations and reflections are excerpts from a study project report [Bu14] (unless marked otherwise, e.g. comments in curly brackets). The project course was held and documented in German (de). While it is not feasible to translate full semantic domain data to English (en), critical data will be translated or summarized selectively in the following.

3 Observations and reflections

The team researched typical competence classification systems to define and describe mutual formulation rules for competencies and agreed on a four-element syntax of category, level, operation verb, and subject (e.g. *technical comprehension*: *calculate fractions*; or *methodical analysis*: *evaluate learning competencies*). They based the categories on the system of Helen Orth [Or99] (*technical, methodical*, *social-communicative*, and *personal* competencies). Levels used the cognitive scale of Bloom's taxonomy [Bl73] (*knowledge*, *comprehension*, *application*, *analysis*, *synthesis*, *evaluation*). From several sources ([Et09], [Ho10], [Kö13], [FUB11], [To13]) a table was compiled (Fig. 1), mapping operation verbs for technical competence (right column, de: Fachkompompetenz) to levels (left column, de: Niveaustufe). The excerpt shows a list of verbs for level *knowledge* (de: Wissen/Erinnern), e.g. ability to *recognize*, *describe*, *define*, *identify*, or *draw*.

Niveaustufe	**Fachkompetenz**		
Wissen / Erinnern	abstimmen anführen angeben auflisten aufzählen benennen berichten beschreiben betonen bezeichnen darstellen definieren	entnehmen erkennen erzählen feststellen finden gliedern identifizieren Kenntnis haben von kennzeichnen messen präsentieren	reproduzieren schildern schreiben sich erinnern skizzieren umreißen wiedergeben wiederholen zeichnen zitieren zuordnen
Verstehen	abgrenzen	extrapolieren	repräsentieren

Fig. 1: excerpt from table mapping levels ("Niveaustufe", left column) to verbs of technical competence ("Fachkompetenz", right column) (excerpted from [Bu14])

The *subject* was extracted individually from specific course content. To align the format of the data, the team developed a form (implemented in Microsoft Word) with a competence matrix per course, based on a template from elementary schools. Fig. 2. shows an excerpt from the competence charting for computer engineering (de: Informatik) from the category *technical* competencies (de: Fachkompetenzen) with competence entries per subject (de: Inhalt), crossmarks on the respective level *knowledge*, *apprehension*, and *application* (de: Stufe Wissen/Erinnern, Verstehen, Anwenden), as well as *formulated competence verbs* underneath, here for entry 1: *knowing* and *denominating* (de: Formulierte Kompetenz: wissen, benennen).

To synchronize apprehension and application of the definition, *one course* (material science 1) was modelled *mutually*. Then, each participant modelled *two mutually selected courses independently* (material science 2, computer-aided design 1) to validate the definition by comparing the five matrix samples per course with regard to reproducibility of their four elements. Unfortunately, systematic analysis of reproducibility was not anticipated in the exploration as an explicit research design but developed by the participants' own, highly commendable initiative. The five deviating matrices were not turned in with the report and cannot be reconstructed ex post, so no specifics can be derived. Looking back, a systematic reflection of specific aspects and degree of reliability of taxonomic competence descriptions would have been a relevant exploration task. This might be of interest for a continuative research question.

Kompetenzerfassung zum Modul F25 (Informatik)

1. Fachkompetenzen

Nr.	Inhalt / Modulbestandteil / Themengebiet	Stufe / Niveau					
		Wissen / Erinnern	Verstehen	Anwenden	Analysieren	Beurteilen / Bewerten	Erweitern / Erschaffen
1	Grundlagen Hardware	X					
2	Grundlagen Betriebssysteme (Unix/Windows)	X					
3	Grundlagen Software	X					
4	Grundlagen von Datensicherheit und Datenschutz	X					
5	Grundlagen der Datenverarbeitung	X					
6	Informations- und Kommunikationsdienste	X	X	X			
7	Datenbanken und Datenbankenmodelle	X					
8	Programmierumgebungen und Programmiersprachen	X	X	X			
9	Datenaustausch	X	X				
10	interne und externe Schnittstellen	X	X				
11	Aufbau von Internetseiten, Homepage, Hypertext	X	X	X			
12	Dienste und Browser	X	X	X			
13	Protokolle und Adressierung	X	X	X			
14	Informationsbeschaffung-, bereitstellung, -suche	X	X	X			

Formulierte Kompetenzen:

1 Kennen, benennen

Fig. 2: Competence matrix for computer engineering (excerpt from appendix of [Bu14])

However, as a conclusion, “for all four criteria {syntax elements}, severe differences could be observed. Competence categories were identified differently, subjects were formulated individually, levels assessed with subjective perception, and verb specification was conducted unequally strong {sic}”.

The team reflected:

- Description of competencies with this basic approach is subjective and therefore cannot be conducted independently from each other in this form.
- To avoid crass differences resulting from subjective experience, expert panels should be assembled who generate those descriptions with the matrix mutually.
- Social and self-competence cannot be assessed and described {sic – based on their stage of expertise in competence modelling.}
- The six {Bloom’s cognitive} levels work only for technical competencies. For all other {categories}, specific competence levels have to be used that express the degree of mastery in this competence type duly.

In consequence, the definition was revised by eliminating social and personal competencies completely because of the mainly technical focus, and by applying a new scale for methodical competence levels (*elementary school*, *secondary school*, *German*

Abitur {comparable to A-Levels or International Baccalaureate Diploma Programme}, and *University*"): Based on the new definition, they completed the further course mapping individually, without further validation. However, this might be attributed rather to a depletion of inspiration for further improvement potential than to fatigue of commitment: Their report covers in fact all 23 mandatory courses from the full six-semester bachelor program (much more than the five examples required), with a scope from natural science basics, over typical mechanical engineering technology to computer aided modelling and simulation.

4 Conclusion

The exploration study demonstrated that

- an established team
- of five capable, highly engaged, and well-cooperating domain experts
- with a recent, widely identical professional background
- from the perspective of a homogenous, single-perspective organizational unit of an educational institution
- after cooperatively defining, aligning, and employing a researched and agreed syntax with a systematic tool

was not sufficient to create a fairly unambiguous, reproducible competence model from their specific domain. The reflection of the process makes the practical barriers for taxonomic modelling vivid and tangible.

The exploratory, selective, and subjective nature of this study puts implications into a limited perspective. No quantitative analysis or factor analysis could be conducted to estimate modelling reliability. It also has to be considered that the domain experts had limited exposure to competence modelling. More experienced competence management experts would likely identify better-suited taxonomies (instead of eliminating social and personal categories altogether, or mapping methodical competencies to stages of an individual education system). Even mapping technical competencies to a purely cognitive scale might be regarded an unspecific approach, bearing inconsistency potential by design.

Yet, this subjective, hands-on example exploration graphically showcases the distinctly perceived difficulties of taxonomic modelling, even in a very narrow field of expertise. Extrapolating from this simplification to a global, multi-lingual, distributed competence model, decentrally managed by domain experts (not competence management experts), some implications can be derived at least for further consideration.

5 Implications

A competence model based on a strict taxonomic model should be assumed – or rather be expected – to be severely subjective, inconsistent, and extensively cumbersome to maintain and extend, at least without significant alignment efforts in modelling and utilization. Inconsistency should be expected to affect all typical syntax elements like the subjects to be competent about, the operations to be competent for, as well as levels and categories. This can be countered by cooperative alignment during creation, maintenance, and utilization of the competence model. This would, however, render such a structure inapplicable as key element of a global, distributed, multi-perspective system.

It is no surprise that a wide range of concepts from an indefinite spectrum of domains is highly elusive to consistent classification. The need for extensive maps of operation verbs (and the demonstrated inconsistent results) indicates that this element of syntax is also highly subjective to context and experience. It should be expected that both, subject and operation verb, cannot rely on a mutually agreed closed structure as part of a decentralized competence model, but require semantic openness in modelling and interpretation. In consequence, they should not be handled as pre-defined categories or attributes, but as semantic data that can be defined, correlated, interpreted, and shared, depending on subjective perspective.

It may also be concluded that level and category did not contribute directly to the specification of a competence: The verb-to-level mapping table indicates that operation verbs were used primarily to identify higher aggregated levels. Categories were only used to assign a competence to the most applicable level taxonomy. There is no example in the data where a competence is specified more in detail by means of the category. In consequence, level and category depend with a cardinality of 1:n directly on the choice of verb resp. subject, they are less specific aggregate attributes, and thus not required for competence specification. The correlation of levels to verbs and of categories to subjects was reflected to be just as subjective as the data itself, escalating inconsistency of the model significantly. They need not (and should not) be constitutive part of a model structure.

6 Outlook

One possible implication is that neither taxonomies, nor syntax definitions, nor algorithmic approaches seem to be sufficient by themselves to guarantee coherence across various contexts, as a by-product of an actual process of competence identification, formulation, and mapping. Rather, coherence of competence maps could actually be considered as outcome of two separate, but highly interdependent processes:

1. compositional[2] modelling to identify, formulate, and map operative occurrences of competencies (e.g. in owners, learning settings, or tasks), by configuring semantic elements according to a compositional syntax, and
2. lexical modelling to define and maintain the semantic logic behind these elements (meaning) for semantic interpretation (e.g. a taxonomy or a domain knowledge graph) according to a lexical syntax.

Those processes would be separate because composing competence occurrences and defining domain knowledge require a diverging perspective and focus. For instance, parsing descriptions of personal experience, courses or job profiles manually or with Natural Language Processing (NLP) can be expected to result in a domain knowledge model that would be rather selective to these contexts than cross-linked for technical lexicality. On the other hand, analysis of technical domain knowledge or parsing technical reports will hardly generate a representative set of formulated competencies how to make use of this knowledge.

But both processes would also be highly interdependent because lexical models provide elements for compositional modelling, and compositional formulations would contain new elements to feed into lexical modelling. Furtherly, competencies are not restricted to elementary subjects (e.g. “recognizes a hammer”) but can comprise complex subjects from a domain knowledge model (e.g. “can operate a hammer to drive a nail” or “can reflect that a hammer is a type of tool”). Therefore, compositional and lexical modelling could possibly share a part of their syntax. If the compositional syntax would be based on an established syntax for lexical use - like semantic triples from the Resource Description Framework (RDF) - it could be possible to incorporate already existing domain knowledge models.

Instead of closed-term taxonomic classifications, more versatile structures such as semantic networks or semantic graphs can be used to define, correlate and interpret semantic elements (like “operation verb” and “subject”, or even to further break down the subject). This would be in line with today’s software reality where more and more personal and social storage systems (e.g. for music, photos, bookmarks, or notes) can be observed to shift from hierarchic folder or category structures to more flexible non-hierarchic interfaces (like multiple tags, tag clouds, or knowledge graph structures). This is explored

[2] Based on the linguistic principle of compositionality by George Boole (also attributed to Gottlob Frege as Frege’s principle)

further in [Da20].

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