Lifelong Competence Development: On the Advantages of Formal Competence-Performance Modeling

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Efficient support, in-depth modeling, and tracking of the development of individual competence is, undoubtedly, a major challenge for interdisciplinary research and development. From our viewpoint, a major problem is the often unclear and sometimes vague approach to competence. Often it is assumed that competence can directly be assessed. Many definitions of competence, however, agree that competence is an abstract, latent quality, which cannot directly be observed. Thus, it is highly difficult to keep track on competence development over time or to compare competencies assessed with different instruments (such as tests, observations, or certain achievements). This article discusses the advantages of a formal competence-performance modeling such as a clear definition of latent competencies and a separation from observable performance (e.g., test results). Other advantages discussed are the possibility of exactly determining a person's competence state, incorporating interdependencies between competencies, and modeling individual learning paths over time.

Keywords: competence, performance, lifelong learning, learning path, competence assessment

1. Introduction

The concept of *competence* is a vital element of today's information and knowledge society. Competence means economic success, for the individual as well as the whole society. The PISA studies (http://pisa.oecd.org), however, have shown that there is need for action in the development and assessment of competencies as well as the classification of competencies.

From our point of view, a major problem when considering individual competence is the unclear differentiation between *latent competence* and *observable performance*. To date a variety of definitions of competence exists (e.g., [1, 2]). The *American Heritage Dictionary of the English Language*, for example, states: "Competence means the state or quality of being adequately or well qualified; a specific range of skill, knowledge or ability". This and many other definitions have in common that they describe competence as an abstract, latent, not directly observable quality. For an adequate development and assessment of competence, however, latent competencies must be associated with observable behavior or achievements. Chomsky [3] distinguished a speaker's competence to use and understand a language and the performance, which includes grammatical mistakes and non-linguistic features like hesitations. The distinction between competence and performance or behavior has of course a much wider application, for instance in the field of knowledge and learning psychology. Still, in practice the concepts of latent competencies and related observable performance are often jumbled up and often it is assumed that competencies can be directly assessed by certain tasks or tests, or even by selfevaluation, like in ePortfolios. This, however, is problematic as demonstrated with the following example:

Imagine an exam in trigonometry. Students might be allowed to use a mathematical formulary and a pocket calculator. If two students master a certain task of the exam, can we conclude that these students do have the same competencies with regard to the task? We cannot; one student might have the necessary competencies to master the task without using the formulary, another student maybe mastered the task only by chance, incidentally choosing the right formula from the formulary. Or imagine three students who did not master the task. One student might lack the competence to fully understand the task and its formulation. Another student might fully understand the task and also might be able to choose the right formula, but maybe this student is not able to use a required function of the calculator. Finally, a third student might have the necessary competencies to master the entire task but might have problems to concentrate on the tasks during an exam. Although all three students did not master the task, they differ considerably from each other with respect to the competencies they lack and therefore in their individual needs on teaching.

This example demonstrates that it is not only necessary to break down certain types of competencies [4], but also to separate competencies from performance and to adapt learning to individual needs. This is especially true for life long learning, when the aim is to have a continuous model of competence development, to track the development over a long time span, and when competencies are assessed with many different instruments (e.g., observations, tests, achievements).

Such aims require a clear and probably standardized, definition of competencies in a given domain and a psychological model that allows distinguishing latent competencies and observable performance.

2. Competence Structures

Knowledge Space Theory (KST) [5, 6, 7], is the basis for several approaches to competence structures, which provides a set-theoretic framework for organizing a domain of knowledge and for representing the knowledge based on *prerequisite relations*. A knowledge domain is represented by a finite set Q of problems. The *knowledge state* of a learner is described by a subset of problems that s/he is able to master. Due to prerequisite relations among the problems of a domain, not all subsets of problems are possible knowledge states. If two problems a, $b \in Q$ are in a prerequisite relation $a \precsim b$, we can assume from mastering problem b a mastering of problem a. To give an example, image five problems of the domain of basic algebra, an addition, a subtraction, a multiplication, a division, and an equation. For five problems the set of all possible knowledge states is 2^5; if we assume that addition, subtraction, multiplication, and division are prerequisites for solving equations, not all 32 knowledge states will occur, because it is highly improbable that a student will be able to solve equations but no addition problems.

The collection of possible knowledge states corresponding to a prerequisite relation, including the empty set $\varnothing$ and the whole set Q, is called a *knowledge structure K*. To account for the fact, that a problem may be solved in different ways and thus may be associated to different sets of prerequisites, the notion of a *prerequisite function* has been introduced, which, as a generalisation of a prerequisite relation, associates a family of subsets of Q with each problem.

In its original formalization, KST is rather behavioristic, focusing on the observable performance without referring to the competencies that underlie that performance. Among others [8, 9], one extension, which incorporates explicit reference to the competencies that are required for mastering the problems of a domain is CPA by Korossy [10, 11]. The basic idea of CPA is to assume a basic set E of abstract, cognitive competencies that are relevant for mastering the problems of a domain. The *competence state* of an individual is the collection of all available competencies of that person, which is not directly observable but can be uncovered on the basis of the observable performance on the problems representing the domain. As in KST, prerequisite relations are described on the set of competencies establishing a *competence structure C*, which contains all possible competence states. Utilizing *interpretation* and *representation functions*, families of subsets of competencies (competence states) can be mapped to problems, which can be mastered with the given competencies and vice versa. By the assignment of competencies to the problems of a domain, also a “problem structure” – which may be a surmise relation or a surmise function - on the set of problems is induced.

To illustrate this approach, assume a knowlegde domain that is represented by a set of four problems (e.g., test items), $Q=\{a, b, c, d\}$. Consider the set $E=\{V, W, X, Y, Z\}$ of competencies that are relevant for solving these problems. The prerequisite relations that exist among these competencies are demonstrated by the And/Or-Graph in Figure 1a. Thus, if a student possesses competence X

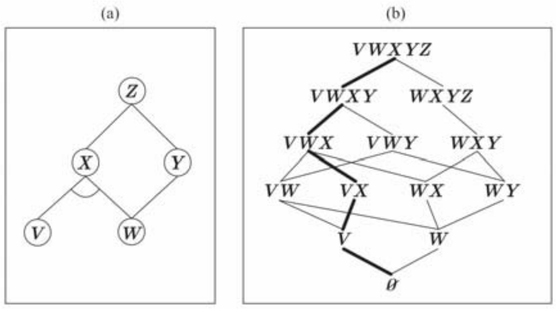

Figure 1. Panel (a) displays the AND/OR-graph for a prerequisite function among five competences (V to Z). The bended line below competence X indicates a logical or. Panel (b) shows the competence structure established by the prerequisite function. The bold line indicates a valid learning path.

we can assume that this student also possesses either competence *V* or *W* or both; if a student possesses competence *Y* we can assume that this student at least possesses also competence *W*. The prerequisite function establishes a competence structure (Figure 1b), which includes only thirteen possible competence states from a total of 2^5 states. Table 1 lists an interpretation function, which associates competence states that are adequate for mastering a given problem. This means, for solving problem *a* one of the two competence states *{V, X}* and *{W, X}* is necessary and sufficient; a student that has one of these two competence states (or a superior one) will be able to master this problem. Given the interpretation function, the representation function specifies the subset of problems that can be solved in each competence state.

Table 1. *Interpretation function.*

Problem	**Competence states**
a	*{V, X}, {W, X}*
b	*{W, Y}*
c	*{V, W, X}, {W, X, Y}*
d	*{W, X, Y, Z}*

The outlined approach entails several advantages. Given the performance, i.e. the subset of problems a student could master, the latent cognitive competencies underlying that problem solving performance can be identified. Due to the utilization of representation and interpretation functions no one-to-one mapping of performance (e.g., the responses to test items) to competencies is required.

3. Applications

In the following, several application areas of CPA in the context of lifelong learning are outlined.

3.1 Longitudinal Observations

With regard to lifelong learning, it is important to keep track on individual development of competencies over a long period of time. CPA allows the mapping of a variety of different assessment instruments of a certain domain to one competence structure. This means that it is possible to identify the actual competencies of a person once with a school exam and many years later with a different instrument, e.g. achievements at the workplace.

This strength of CPA was applied, for example, in the domain of children's understanding time, distance, and velocity concepts, as a tool for modeling the developmental course [12] including misconceptions. In recent work learning paths are utilized to analyze longitudinal data in this domain.

3.2 Competence Development

Besides identifying competencies, a further major advantage of CPA is that it allows determining a person's current competence level by personalized, adaptive competence testing; furthermore individual learning paths can be defined on the competence level. Due to the prerequisite relations between competencies the development of competencies cannot occur along arbitrary paths. Referring to the example presented before, a student who is in the competence state *{W, Y}* cannot directly proceed to competence state *{V, W, X, Y, Z}* because competencies *V, X,* and *Z* are lacking (Figure 1b demonstrates a valid learning path for this example). Thus, CPA allows very detailed planning of competence development along learning paths and adapting teaching to individual needs with regard to learning objectives. If a student is, for example, in competence state *{W, Y}* it would be most efficient to teach this student competence *X* instead of *V* in order to reach competence state *{W, X, Y, Z}*, which allows the student to master problem *d*.

3.3 Technology-enhanced Learning

During the last years, the approaches of KST and CPA were increasingly integrated into adaptive eLearning systems [13] such as the research prototypes APeLS (http://css.uni-graz.at/demos/apels) or RATH (http://css.uni-graz.at/rath), as well as the successful commercial eLearning platform ALEKS (http://www.aleks.com). Moreover, these formal, computational approaches contribute to state-of-the-art eLearning projects under the IST framework (e.g., EASEL, EleGI, iCLASS, or ELEKTRA).

3.4 ePortfolios

Another good example to demonstrate the importance of clear definitions of competencies and their separation from assessment instruments are ePortfolios. During the last years ePortfolios gained more and more popularity. These portfolios are dynamic collections of authentic and diverse evidence that represent which competencies a person has developed over time [14]. They provide (a) profiles of competencies, (b) opportunities for learners to document their competencies in different contexts, (c) opportunities for reflection in different contexts to integrate learning experiences, and (d) opportunities for a more holistic approach to learning [15]. ePortfolios' gain of currency is fostered by the European Union by the initiative “2010 – ePortfolio for all” (http://www.eifel.org).

To achieve such dynamic collections of competencies, it is necessary to develop standardized competence databases, which clearly define competencies of certain knowledge domains. Only if the competencies of a person from one part of Europe assessed with a school test are directly comparable to the competencies of a person from another part of Europe assessed by an evaluation at the workplace, this initiative can be successful.

5. Conclusion

Today, we are facing an inflationary increase of test instruments and related competencies. One reason is that competencies are often not clearly separated from observable performance. However, to improve lifelong individual competence development in terms of learning success, individual career opportunities, and costs, it is necessary for future research and development to address major challenges. These include exact definitions of competencies and the modeling of interdependencies and learning paths. Moreover, efficient lifelong competence development requires the possibility to map a variety of assessment instruments to a standardized set of competencies in order to make competencies comparable, and to allow trans-regional accreditation of personal competence.

CPA, as an extension of KST, is a sound and well-elaborated psychological framework, which can be utilized to address these challenges. A major advantage of CPA is its formal mathematical nature, which can easily be implemented in computational systems, such as adaptive tutorial systems.

Still, there exist some demands on recent and future research in the context of CPA. For example, it is necessary to model errors, which likely occur in empirical responses to test items (i.e., careless errors and lucky guesses). This requires the extension of deterministic models by probabilistic ones [16]. Another major issue is the validation of prerequisite relations among competencies and the resulting competence structures. Currently, various coefficient-based methods exist to compute the “fit” of a proposed competence (or knowledge) structure to a given set of empirical response data [17]. Recent research develops more sophisticated, simulation-based methods, e.g. Markhoff-chain Monte Carlo procedures.

Even if future work must address existing problems, CPA provides a promising theoretical and methodological basis for the requirements of modeling and assessing lifelong competence development.

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