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Knowledge, Skills, and Competences

Descriptors for Engineering Education

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Abstract— **Since the European Parliament has given an according recommendation, qualifications are to be described in terms of knowledge, skills, and competences. In this paper, these terms are redefined in a way that they are put into relation to learning-models, thus making possible to describe qualifications in engineering education in a more rigorous and verifiable way.**

Keywords- education;qualifications frameworks; assessment

I. INTRODUCTION

In December 2004, the Ministers of 32 European countries, responsible for vocational education and training, decided to create a European Qualifications Framework (EQF). The European Commission presented a proposal for this framework, which in a revised version was confirmed in 2008 by the European Parliament [1] with the explicit statement that it might be applicable not only to vocational education and training, but also to general and higher education.

In the corresponding documents, it is requested that the different levels of qualifications be described in terms of knowledge, skills, and competences, which in turn requires that the latter might be assessed on a largely objective basis. That would not be possible without a clear definition of these terms.

This is the point where first difficulties arise, since the different branches of science use these terms in different contexts and with different meanings. However, as largely objective comparison of learning outcomes is the main aim, science-based definitions only will be considered in this paper. Hermeneutics will not be discussed here, though these might give rise to interesting disputations.

Another restriction suggests itself: Since learning-outcomes are to be assessed, terms should be defined with strong relation to accepted learning theories.

Therefore, a short introduction to some essentials of a learning model will be presented that gives insight into the different steps of learning. With respect to this model, different definitions of terms will be discussed, ending up in a suggestion for their re-definition. As a consequence, some methods of assessing knowledge, skills and competences will be considered.

II. FIVE STEPS OF A LEARNING CYCLE

It is meanwhile widely accepted that learning is a cyclic process (see for instance [2] - [4]). Following [5], the steps of a learning cycle are given as in Fig. 1.

The different steps of learning in a cycle are:

1. Get to know facts

   This is the most basic learning step. It serves to memorize basic pieces of information. This type of retrievable information is called *factual knowledge* in Bloom's revised taxonomy of learning [6].

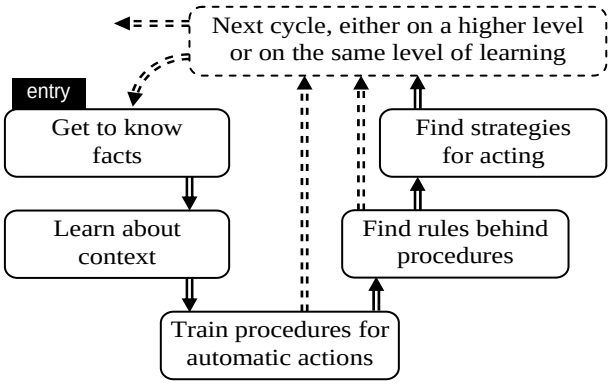

Figure 1. Diagram of a learning cycle on a specific level of learning (from [5] with permission by IEEE)

2. Learn about context

   Knowledge on facts must be linked to other pieces of information in a context. Facts could have completely different meanings in different contexts.
   This might be demonstrated by the example of memorizing (English) vocabulary. If, for instance, a newspaper headline reads "The president is holding a ball", is he then having an elastic sphere in his hands, or is he heading a social event?
   Knowledge about context is called *conceptual knowledge* in Bloom's revised taxonomy. It must be learned like learning facts.

3. Train procedures for automatic reactions

   Knowledge about facts in contexts is the prerequisite for adequate reactions to changing situations. If these reactions happen without or nearly without conscious awareness, then they are memorized in the implicit memory [7], which is also called procedural or non-declarative. The corresponding process of learning is a *training-process* in this case. Following Squire [8], trained procedures are stored in the striatum, which is a part of the brain. Neuroscientists call that part of the memory *procedural*, while they call these procedures *skills* and *habits.*
   Note that this usage of wording is closer to the colloquial use of this term, and much more specialized than the usage of the term "skills" by some schools of educational scientists.

4. Find rules behind procedures

   A very important step in learning is to find out rules that govern procedures and to store them in memory. Their conscious application is basis for thoughtful action. Following Squire [8], these procedures are stored in parts of the brain that are different from the striatum. They are parts of the declarative memory. Since in contrast to training procedures, this type of learning needs a purposeful action, and since it is stored in other parts of the brain, finding rules cannot possibly belong to the same category of learning as compared to training of procedures.
   Following [5], this type of knowledge is called *canonical* [1], since it comprises awareness of rules.
   Acquisition of canonical knowledge needs analytic capabilities.

5. Find strategies for acting

   The most advanced type of learning evolves from thinking about what would happen, if rules that are valid in one particular context would be applied to another context, or what would happen, if rules would be broken. Possible actions might then be stored as potential strategies for handling future events.
   Following [5], this type of knowledge is called *strategical*. It is the basis for creative thinking.

A cycle of learning starts typically with the acquisition of factual and conceptual knowledge in Bloom's sense. The memorized information is stored in the declarative memory.

Provided that the information could be retrieved by the learner at will, this step of learning is seen to be successful: That piece of information has been learned by heart.

Steps 1 and 2 of learning are usually followed by a training period, which leaves procedural knowledge in Bloom's sense in the procedural memory. The ability to retrieve this information *and* to apply it is called *skillful acting* in Squire's wordings.

Often, the cycle is then closed by starting another cycle, without using steps 4 or 5, i.e. the cycle finishes with the acquisition of skills (in the colloquial sense or in terms of neuroscientists).

A deeper understanding can only be acquired, if the three previous steps of learning are followed by step number four, in which rules behind procedures are discovered.

Bloom and colleagues did not yet have access to newer neurological results when they created their model. Therefore, they did not distinguish between information about automatic reactions and information on thoughtful action. Therefore, they called both of them *procedural knowledge*.

Based on the newer findings, however, which were summarized by Squire, it is known that these types of information differ not only by the methodology, with which they are acquired, but also by the location where they are stored. Therefore, a clear distinction must be made between learning results from steps 3 and 4.

In most cases, learning cycles are finished after step 4. Indeed, all days' situations might be successfully handled by application of procedural and canonical knowledge.

Step 5 is performed on highest levels of learning only. It concerns memorizing of potential actions and reactions for future events. It is not necessarily result of a verbalized way of

[1] canon = rule

thinking. It rather could be the result of a figurative way of thinking, too.

After completion of a cycle, seldom after step 2, usually either after step 3, or 4, or 5, another cycle will be initiated, either on the same level of learning or at a higher level of learning.

Having these processes in mind, a critical analysis of terms and definitions used in qualifications is now possible.

III. The EQF-Definitions for Knowledge, Skills, and Competences

Following a convention signed by the council of Europe and the UNESCO [9], qualifications are papers giving evidence for achieved degrees, diplomas or other certificates issued by a competent authority attesting the successful completion of a higher education program. Qualifications frameworks serve to compare qualifications awarded by different institutions, often from different countries.

The European qualifications framework (EQF) [10] differs from prior attempts to compare qualifications, amongst others, by categorizing learning objectives using the *three qualifiers* "knowledge", "skills", and "competences". It is a particular feature of the EQF that it gives definitions of meaning of these qualifiers.

This is not a matter of course, since methods used in educational science are dominated by hermeneutical approaches, which live from interpretations. Rigorous definitions would leave not much space for these.

Bloom's taxonomy is a nice example of advantages and disadvantages of that approach: Categories and in particular descriptions in Bloom's original taxonomy concerning the cognitive domain [11] deviate from Bloom's revised taxonomy [6]. Essentially, this change was not caused by falsification of a model, but by re-interpretation.

As a consequence, assessment of learning outcomes that one and the same person has demonstrated at a given point in time, could change (slightly) by changing the set of interpretation rules in the two versions of Bloom's taxonomy.

This change was made possible by categorizing all different results of learning processes as "knowledge" in a wider sense, and by distinguishing different types of knowledge by attributes that could be replaced easily by others.

The advantage of this proceeding is that initially many people could agree to that approach, while fine-tuning is possible until a wide consensus is achieved.

The disadvantage is missing clarity and reliability.

By the way, interpretations of the other two domains of Bloom's taxonomy, the affective domain [12] and the psychomotor domain [13], were much less successful, since until now, interpretations are too much diverging, which again demonstrates a weakness of the hermeneutic approach.

Nevertheless, Bloom's taxonomy has its undisputed and highly appreciated value, since it cleared the way for the application of scientific methods, in particular statistical methods, to the evaluation of learning outcomes.

This is exactly what is needed in order to compare intended learning objectives and actual learning outcomes of educational programs, provided the results of comparison leave only little space for individual interpretation.

This is why clear definitions are needed.

Indeed, there are many different paraphrases on the meaning of the qualifiers "knowledge", "skills", and "competences". Surprisingly, however, most of them are not very rigorous. They are often quite imprecise, or they are even contradictory.

The late F.E. Weinert, a well-reputed psychologist, who did not have the opportunity to get to know newer theories of learning, even stated in 2001: "There is no basis for a theoretically grounded definition or classification from the seemingly endless inventory of the ways the term competence is used" [14].

There appears to be a tendency, thus, to avoid the definition of terms. This applies also to prominent predecessors of the European Qualifications Framework. These are the Tuning projects [15], and the Dublin Descriptors [16], [17], where the impression arises that the authors have a clear imagination of what they mean by terms like "skills" and "competences", but where they obviously assume that the readers share this imagination, thus making it unnecessary to define the terms.

This is different in the European Qualifications Framework [18], where the attempt is made to create definitions of terms that could be commonly accepted by educational scientists as well as of psychologists, of natural scientists as well as of representatives of humanities and of social sciences. They do not coincide, however, with Bloom's terms.

The EQF-definitions are given as follows:

1. *knowledge* means the outcome of the assimilation of information through learning. Knowledge is the body of facts, principles, theories and practices that is related to a field of work or study. In the context of this framework, knowledge is described as theoretical and/or factual.
2. *skills* means the ability to apply knowledge and use know-how to complete tasks and solve problems. In the context of this framework, skills are described as cognitive (involving the use of logical, intuitive and creative thinking) or practical (involving manual dexterity and the use of methods, materials, tools and instruments).
3. *competence* means the proven ability to use knowledge, skills and personal, social and/or methodological abilities, in work or study situations and in professional and personal development. In the context of the EQF, competence is described in terms of responsibility and autonomy.

This is the welcome attempt to reconcile scientists of different disciplines. However, there is still a need to improve

the given definitions, since in particular skills and competences could not be distinguished clearly by these definitions.

The EQF-definition of knowledge, for instance, includes terms like "theories" and "practices". With reference to the above cited model of learning, it comprises attributes of all different steps of learning, thus making impossible to clearly distinguish between different categories of the process of learning.

Does knowledge about theories in the EQF-sense include know-how of their application? If so, why is it then necessary to introduce the qualifiers "skills" and "competences"?

It might be supposed that the creators of the EQF-definitions intended to separate pure retrieval of information from application of stored procedures. Unfortunately, this has not been clearly expressed in the definition.

A similar critique applies for the EQF-definition of skills that includes the "use of logical, intuitive and creative thinking", while "competence" is defined as the "proven ability to use knowledge, …, social and/or methodological abilities, in work or study …".

What is the essential difference between these categories? Is it the difference between "use" and the "ability" to use something? Or is it the requirement that in the definition of the term "competence" the attribute "proven" is used?

Having these questions in mind, it appears as if the EQF-definitions suffer from soft compromises that prevent rigorous classification.

IV. The 4ING-Definitions for Knowledge, Skills, and Competences

4ING [19], the umbrella organization of the four councils of schools of engineering and of computer science and technology at German research universities, therefore, suggests to use a definition that is based on the learning model from section I, and where qualifiers are defined as follows:

1. *Knowledge* related to a field of work or study, means the learnt, retrievable information on facts, the context, to which facts are associated, and the rules interrelating facts to contexts.
2. *Skills* means an ability that has been acquired by training and that makes use of the implicit memory [2], to apply knowledge to *standard* situations, and to use know-how to complete *standard* tasks, and to solve *standard* problems.
3. *Competence* means the proven ability to autonomously recognize interrelations between facts and the contexts to which they are linked, to apply this ability to systematically develop new methods, and, if indicated, to apply them to changed situations. This includes application to work or study situations, and in professional and personal development.

A strong interrelation to Bloom's revised taxonomy of learning and to the cited learning model is seen, since

- knowledge in the 4ING-sense could be measured as retrievable information of factual and conceptual knowledge as defined by Bloom,
- skills in the 4ING-sense would be found as implicit, procedural knowledge (the latter being defined as in Bloom's taxonomy), and
- competences would be classified as application and further development of declarative, procedural knowledge, i.e. as canonical or strategical knowledge as defined in [5].

In a strongly condensed form, it might be said that in the sense of the 4ING-definitions,

- knowledge is learnt by heart,
- skills are acquired by training,
- competence is developed by using sense and intellect.

V. Measuring Knowledge, Skills, and Competences

Having in mind that the European Qualifications Framework defines "qualification" as a formal outcome of an assessment and validation process [18] [… stating] that an individual has achieved learning outcomes to given standards, it is necessary to *measure* knowledge, skills and competences.

This is not too difficult in case of testing knowledge, since knowledge can be retrieved, by definition. It is also obvious that knowledge in the sense of the 4ING-definition might be tested on different levels, since it relates to learning cycles.

A simple means for testing knowledge would be for instance a multiple choice test or cloze text. As an example for an inquiry on different levels, consider the question for the correct formula of Ohm's law. When testing a pupil in the last class of secondary school, a relation between voltage and current could be asked for, while on a bachelor-level, a relation between current-density and electrical field might be the required result [3].

Questions like these would be typical questions for facts in a context and the rules governing these facts. A correct response would not yet tell anything about the ability of the respondent to apply this law to a standard problem.

Indeed, one of the present authors once asked a sophomore student in an oral examination for Ohm's law, which the

[2] Earlier definitions given by 4ING did not yet include the attributive clause "and that makes use of the implicit memory". Also, the clause "that has been acquired by training" was not yet included in earlier versions of the 4ING-definitions. The latter wording has already been used by WordNet [20], an electronic lexical database that is being maintained at the Cognitive Science Laboratory of Princeton University.

[3] It should go without saying that a careful formulation of questions is needed in order that candidates are able to recognize what is expected.

student answered with a correct formula. The following question, what the symbols in the formula would mean, however, could not be answered satisfyingly: The student had some knowledge in the sense of retrievable information, but he certainly had not yet achieved competence, and, as it turned out later, he even did not have the necessary skills.

Within the framework of 4ING-definitions, skills differ from knowledge by that the learner needs not only to retrieve some information, but that s/he must also be able to apply an appropriate, *trained* procedure to solve a standard problem.

In contrast to competences, skills are based on implicit, procedural memory, while competences make use of the explicit memory. I.e.: applying skills does not necessarily require reflecting what one is doing.

The above explanation might be easily accepted for the psychomotor domain: Peeling an egg or driving a bicycle is a skill, not a competence.

Ít is more difficult to transfer this definition to more abstract domains. However, an example shows that this act of transfer is not only possible, it is even sensible, rather.

Every bachelor of engineering knows for instance how to solve a linear, ordinary differential equation with constant coefficients by the method of Laplace-transform. Once the problem is identified, it might be solved by completely schematically applied procedures. Even the steps of transform and inverse transform will be performed without reflecting the mathematics of complex integration, and just by reading out tables. This method of solving a certain type of differential equations is thus a skill in the sense of the 4ING-definition.

Testing for skills using the 4ING-definition might be done by asking for the solution of standard problems that could be solved by standard procedures, which are applied automatically and without intensive reflection of the problem, and that have been trained during studies. Actually, most written exams in engineering subjects do test candidates for skills.

Using the 4ING-definition, even assessing competences is a solvable task. With reference to the definition, it requires posing non-standard problems in the field of study or work.

Problems could be posed and solved in the context of a larger home-work, or by working out a presentation in a seminar, or by giving a more complex problem to a group that has to solve it as a team, or by demanding to work-out a complex thesis etc.

In any case, supervisors have to pose the problems very carefully, such that students must give evidence for their ability to recognize relations between facts, and to apply this information for problem solution. Supervisors must urge candidates to give account of all their decisions such that the latter could be evaluated.

Assessing competences is thus a highly demanding task for supervisors. It might well be that this is one of the reasons why some people declare that it would be impossible to test for competences. However, this is disproved day-to-day by those working successfully in human resources management.

VI. Competence Profiles

A field of work or study, in which knowledge, skills, and competences are to be assessed, might be more or less narrow, or the requirements for achieving a particular level might be higher or lower. It is obvious that a good result of assessment could be easier achieved for a narrower field or for lower requirements. A too vague specification of the field of work or study, however, is certainly not a good idea, if transparency and clarity are the main aims of using a qualifications framework.

While the European Qualifications Framework (EQF) and some other frameworks clearly define levels, most of them including the EQF do not even specify width of knowledge, broadness of skills, or depth of competences, nor do they clearly tell whether their requirements for achieving a certain level must be achieved in full, or in the average, by every candidate, or by the majority of a cohort. This is certainly a serious weak point that must be overcome urgently.

A first step into direction of a possible solution to these problems would be a detailed description of the concrete, intended learning outcomes of a field of work or study.

During the last three years, so-called sectoral qualifications frameworks have been created that apply the categorizations of the European Qualifications Framework to a coherent group of professional subjects. An example is the sectoral qualifications framework for engineers and computer scientists for the bachelor-, master-, and doctorate-level that has been worked out by 4ING [21].

In parallel, an attempt has been made to create a national qualifications framework in Germany [22]. Unfortunately, this framework is not compatible with the European Qualifications Framework. Anyway, it brings in a further categorization of competences that has already been incorporated into the 4ING-definition of the term “competence”: It is the differentiation between subject-specific competences on one hand, and self-competences, and social-competences on the other hand. (See fig. 2). The latter are sometimes called “soft skills”, or “generic skills”, though part of them are not necessarily skills in the sense of neuroscientists or in the sense of the 4ING-definitions.

Virtually all significant qualifications frameworks consider educational careers only that follow a straight way. This means that qualifications levels have been achieved in an increasing order from lower to higher, and ending up in one particular specialized professional field. More than one specialization is not normally taken into account.

However, there are enough persons having qualifications in more than one field of profession.

As an example, consider an artist with a qualification on level 7 in musical sciences, and who had a vocational training in building musical instruments first, and that finished with qualifications-level 5. It might well be that competences had been achieved during the first educational period that either are not required in the second educational period, or that were assessed to have a higher level than the average level of the first qualification, and that could be transferred to the second

<table>
<tr><td colspan="4">(level indicator)</td></tr>
<tr><td>knowledge</td><td>skills</td><td colspan="2">competences</td></tr>
<tr><td rowspan="2" colspan="2"></td><td>subject-specific</td><td>personal</td></tr>
<tr><td></td><td>social | individual</td></tr>
<tr><td rowspan="4">learnt, retrievable information
on facts, the context, to which facts are associated, and the rules inter-relating facts to contexts; related to a field of work or study.</td><td rowspan="4">an ability that has been acquired by training, and that makes use of the implicit memory, to apply knowledge to standard situations, and to use know-how to complete standard tasks, and to solve standard problems.</td><td colspan="2">the proven ability to autonomously recognize interrelations between facts and the contexts
to which they are linked, to apply this ability to systematically develop new methods, and,
if indicated, to apply them to changed situations in a</td></tr>
<tr><td>subject-specific</td><td>social | personal</td></tr>
<tr><td colspan="2">environment</td></tr>
</table>

Figure 2. Schematic of descriptors for knowledge, skills, and competences, including generic competences

one. Such a situation could not be described adequately by most important qualifications frameworks.

Thus, for an adequate assessment, it does not suffice to specify the highest level of qualifications. Rather, any assessment must be accompanied by specifications of what has been assessed, in what professional field, in what width (i.e. which subfields are covered), and on what level. The result would be a *profile* of knowledge, skills, and competences. Such profiles are shown in Figs. 3 and 4.

Fig. 3 shows a profile of someone who has achieved level 6 in some area of expertise ("field 1" in this example), and who has considerably lower knowledge, skills, and competences in two other fields ("field 2" and "field 3"). Also social and individual skills and competences are attested on different levels.

In contrast, Fig. 4 shows the profile of an individual with the same level of knowledge, skills and competences in field 1, but with enhanced levels of knowledge, skills and competences in field 2 and field 3 of expertise, as well as in the fields of social and individual competences.

These two examples reveal two problems that have not yet been solved by the European Qualifications Framework and other national qualifications frameworks.

If fields 1, 2, and 3 are rather narrow, but complementary fields that together form a broader field of expertise, should then a candidate with a profile following Fig. 3 be given the qualification level 6? And should a candidate with a profile following Fig. 4 be given the same qualification as to the first candidate?

A competence profile is thus much more meaningful than a simple qualifications level!

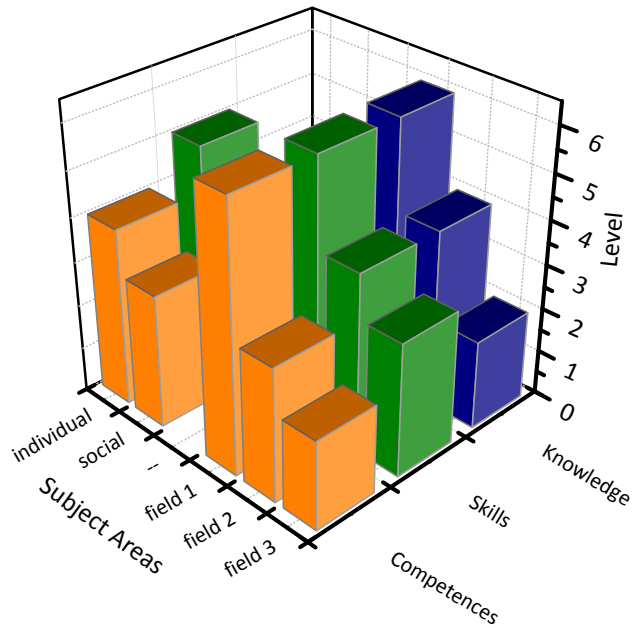

Figure 3. Competence profile with limited width on level 6

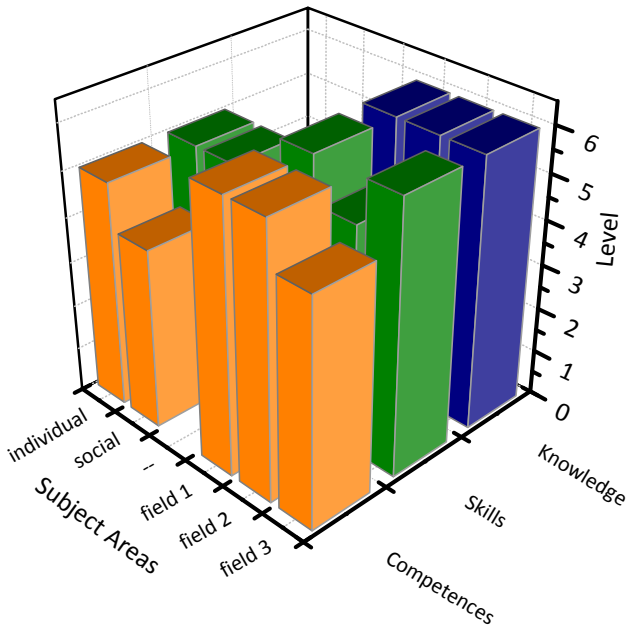

Figure 4. Competence profile with a wider width

4ING suggests, therefore, completing qualifications frameworks, in particular the European Qualifications Framework and related national frameworks, in a way that such profiles would be specified following commonly accepted rules. A characterization by just one number, namely the level, is certainly not enough.

VII. Conclusion and Outlook

Qualifications frameworks are tools for transparency and comparability of qualifications. The EQF uses the categories "knowledge", "skills", and "competences" to describe qualifications on several levels. It has been demonstrated that a more rigorous definition of these categories could be given based on accepted learning models.

With these definitions, "measuring specifications" are made possible that enable educators to assess whether a certain level of qualification has been achieved.

A suggestion has been made to better characterize competences, and to specify qualifications profiles in order that they could be used as tools for comparison. However, to make that tool efficient and effective, much remains to do.

A further development of qualifications frameworks with respect to improved competence profiles appears to be sensible.

Such an improved framework might include refinement of the class of subject-specific competences, e.g. by subdivision into Bloom's taxa of being able to analyze, to evaluate, and to create.

Another focus might be a thorough analysis of individual and social skills and competences. These are certainly not exclusively competences in the sense of the 4ING-definitions. In fact, they are a combination of specialized knowledge, skills, and competences in some subfields of psychology and sociology.

For a classification into one particular level of qualifications, it must be clarified how this level is determined from particular levels of the profile.

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