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Comparison and Evaluation of Learning Outcomes from an International Perspective: Development of a Best-Practice Process

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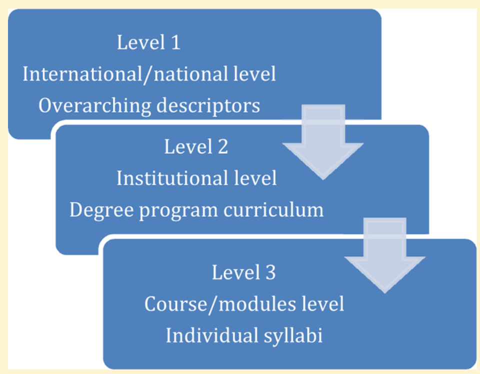
Supporting Information



ABSTRACT: Chemistry education focused on learning outcomes is increasingly practiced, providing new opportunities for international comparisons. The interest in intended learning outcomes and constructive alignment has grown in many parts of the world due to both research in higher education and political decisions. In an International Union of Pure and Applied Chemistry (IUPAC) project, we have developed a method of using critical evaluation of learning outcomes and descriptors at international, national, and institutional levels to enhance learner-centered chemistry education. This method is process-focused, aimed at learning by sharing and comparing practices around the world. Three overarching documents for the chemistry bachelor from the USA, Europe and Australia were compared. The differences were found to be more in style than in content. A tool for self-analysis was constructed to evaluate how learning outcomes for courses and modules are linked to each other and to learning outcomes for educational programs and how the expected learning outcomes can be aligned with learning activities and assessment. We conclude that the method can be used to elucidate the correspondence between learning outcomes at different levels, and the constructive alignment between learning outcomes, learning activities and assessment. The process gives new perspectives and shared knowledge. Chemistry education may need to be different depending on local considerations, and awareness of these differences is of value for further development.

KEYWORDS: *Upper Division Graduate, Curriculum, Professional Development, Student-Centered Learning*

Chemistry has always been an area where theory meets practice. Accordingly students are expected to acquire a broad range of competencies. These can be articulated in intended learning outcomes, which are statements of what a learner is expected to know, understand and/or be able to demonstrate after completion of a process of learning. A hypothetical example of an intended learning outcome could be:

> *The student should be able to interpret data obtained from laboratory observations and measurements in terms of their significance and relate them to appropriate theory.*

The interest in intended learning outcomes and constructive alignment has grown in many parts of the world due to both research advocating their use in higher education[1] as well as political decisions, e.g., the Bologna process.[2] Learning outcomes place the focus on the student and his or her learning, rather than on the teacher and the content of the course. This has been suggested to lead to student-centered chemistry education with students becoming more active learners.[3] Fostering the identification of learning outcomes and competencies in combination with other actions could give both short- and long-term positive effects.[4] Learning outcomes might of course also be used in a detrimental way, leading to e.g. perfunctory practice, where there is a narrow focus on examining limited learning outcomes, giving no support or even room for the students and teachers to explore and develop in creative but unforeseen ways. This would stifle student learning and curiosity, and not allow the "big chemists" of the future to grow. To avoid the pitfalls, therefore, it is important to be aware of and maybe take part in the ongoing debate about learning outcomes as a part of a trend toward "new public management" in higher education (see, e.g., refs 5 and 6).

As learning outcome-driven higher education is increasingly practiced, there are new opportunities for discussions and comparisons from an international perspective. The expressed formulation of what students need to know and be able to do facilitates discussions and considerations of alternatives to the current practice. Documents may be produced at international, national and institutional levels, and such documents can, among other things, define objectives and goals for

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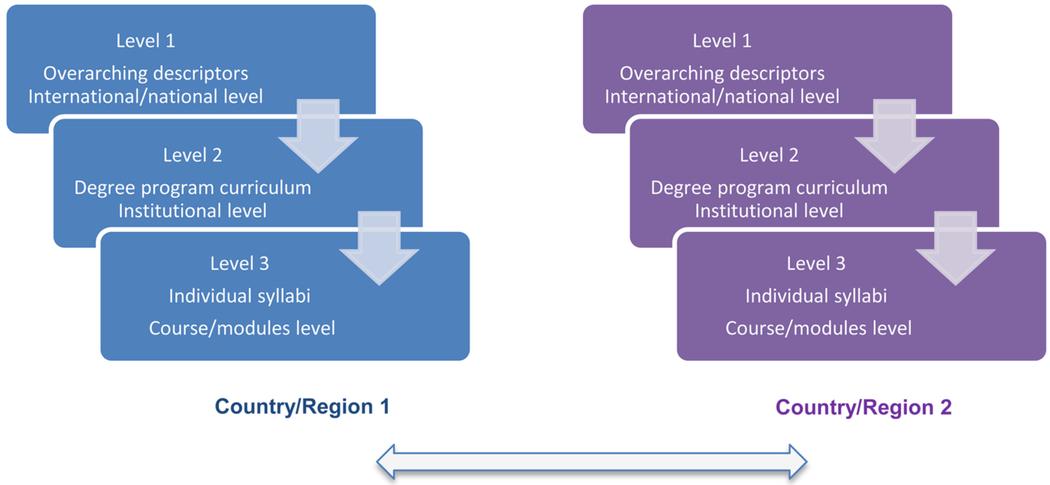

Figure 1. A framework model of learning outcomes at different levels of the regulatory hierarchy in higher education as well as the dimensions of comparisons employed in the project.

accreditation or approval of programs. It is, however, a difficult task to analyze the relevant documents and to find a way of using them in a constructive way. Two highly relevant issues arise from this problem. First, what are the essential competencies that graduates in chemistry should demonstrate, according to the range of documents that have been written at the different levels, from different systems, serving different purposes, and have these documents actually captured the essentials? Second, how can the chemistry educator get a good overview of the different parts of a chemistry program in order to be able to ensure that there is consistency in the learning outcomes throughout the hierarchy of documents, right from individual course level, up through to the guidelines that are issued at national and international levels? Related to this and no less important is of course, how is this reflected in practice?

In an International Union of Pure and Applied Chemistry (IUPAC) project, we have therefore developed a process-focused method, designed for learning by sharing and comparing chemistry programs and to enhance best practice in the use of learning outcomes. A tool to facilitate this process has also been developed. We have focused on skills and competencies, rather than knowledge and content. At the heart of this approach to deal with the issues raised above is critical comparison of the various documents coupled with discussions between chemistry educators.

Unlike other IUPAC projects that aim at standardization (e.g., nomenclature), the purpose here is not conformity; there are reasons for chemistry degree programs to be distinct at universities in different parts of the world. Resources, socio-economic factors, industry expectations, cultural traditions, education systems, etc. can all affect the details of chemistry programs. Rather than striving for conformity, new perspectives and shared knowledge are used in this project for inspiration and awareness of differences. Comparisons across degree programs not only provide possibilities to change when appropriate, but also to think through an approach and stick to that. While learning outcomes have been discussed as part of the overall methodology of quality assurance,[7] our aim is quality enhancement.

A PROCESS-FOCUSED METHOD FOR INTERNATIONAL COMPARISON

Intended learning outcomes are used on many levels, from overarching documents at the international/national level, to degree program curricula at the institutional level, to individual syllabi at the courses/modules level (Figure 1). Figure 1 is a simplified picture focusing on the relationships between documents at different levels, giving a schematic representation of the formal documents describing intended learning outcomes and the hierarchical impact. Accordingly, there are significant variations in learning outcomes at these different levels, influenced by the different purposes of these documents and the interest of various stakeholders considered in drafting them (for more detailed discussions of models of higher education governance, interaction of university with stakeholders and the influence of stakeholders on learning outcomes and curriculum design, see, e.g., refs 8−11)

The process developed in this project encompasses the comparison of learning outcomes along two dimensions. First, comparisons of learning outcomes in documents at corresponding levels from different countries/regions are made. This allows a comparison and evaluation of what are perceived to be the core skills and competencies for a graduate in chemistry. Second, comparisons are made across the various levels of documents. Even though the project does not suggest a certain setup of learning outcomes, consistency between learning outcomes across the different levels within a system is clearly important for a coherent system that enhances student learning. In drilling down to the course/module level, this analysis also examines the constructive alignment between the learning outcomes, learning activities and assessments within a particular system.

The analysis process during the project took the form of two consecutive workshops with participants who were chemistry educators and chemistry education researchers from the USA, Australia, Finland, France, Germany, The Netherlands and Sweden. After initial discussions on the overall project design during the first workshop, a matrix comparing the overarching level 1 documents was constructed prior to the second workshop by a task force consisting of two of the project members and incorporated into a draft tool for self-analysis

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(see below). This tool was sent to the other project members in preparation for the second workshop.

The matrix focused on the overarching descriptors at the international or national level (level 1). The ACS guidelines from the USA,[12] the Eurobachelor from Europe,[13] and the Learning and Teaching Academic Standards (LTAS) from Australia[14] describing intended skills and competencies for bachelor degrees in chemistry were analyzed. These documents were created mainly by chemists within universities, but with the intention to prepare students both for employment and further studies. As noted above, the formulations in these documents are influenced both by the purpose for which they were created (profession-wide standards, accreditation, international cooperation, regulatory frameworks etc.) and the interests of different stakeholders that are in some way connected to and influence chemistry education, be it from industry, government, university or more broadly from society. Further discussions can be found in the original documents.[12−14]

The tool for self-analysis also included sections facilitating comparisons across the different levels of learning outcomes (Figure 1), allowing comparisons across educational systems, internal consistency across the levels within these systems, as well as constructive alignment at the individual course levels.

The second workshop was dedicated to discussion, comparison and further analysis, including critique of this initial material. All project members engaged first in further discussions of the overarching (level 1) documents. In addition to examining the existing content in these documents, the participants also discussed more generally whether any aspects important to chemistry education were missing from these documents, based on their own research expertise and teaching experience. The consensus was that all the important competencies that were identified during the process were dealt with in at least one of the overarching documents, though not always given the same weight or emphasis. Content, style and emphasis of the documents were furthermore compared, critically evaluated and discussed. This process, involving the international panel of participants, confirmed the main conclusions of the original comparison of the level 1 documents as summarized in the matrix constructed by the task force. The discussions also provided a number of indications for further development, which led to the final categorization as used in the refined version of the matrix (Supporting Information; further discussions below).

Continuing on to the degree curriculum and course/module levels (levels 2 and 3, respectively), the workshop participants analyzed documentation at the bachelor level from their respective institutions, using the tool for self-analysis (Supporting Information). The matrix comparing the level 1 documents had been divided according to the categories and incorporated into the tool, enabling investigation of how consistent the learning outcomes for the degree (level 2) are with the overarching descriptors at the national/international (level 1), as well as how well the learning outcomes for courses or modules (level 3) are in turn consistent with the degree level learning outcomes. At this point, increased focus was placed on more concrete details of course requirements and constructive alignment within the courses, as local learning outcomes for chemistry bachelor programs were gathered and analyzed.

A key feature of the process adopted at and between the workshops is the heavy emphasis on discussions and critical analysis that took place between participants from around the world. By drilling down through the levels of documents, consistency across the levels in the hierarchy of documents, both in words and in practice, could be explicitly examined, in addition to the identification of skills and competencies that are included. There was continuous evaluation and development of both the tool and the process itself. The comparative approach both across and within the borders of educational systems was an essential part of developing a "best practice" process for such analyses that can be applied more widely.

In the following section, further discussions are provided about the insights gained from the comparisons of the different documents.

EVALUATION OF THE OVERARCHING DESCRIPTORS

The overarching documents concerning the chemistry bachelor from Europe, USA and Australia, had both similarities and differences. At a first glance they seemed quite different. However, after a more thorough investigation, it appeared that they were more different in style than in content (see the matrices in the tool for self-analysis, Supporting Information).

Both the Eurobachelor and the Learning and Teaching Academic Standards from Australia contained separate intended learning outcomes, while the ACS guidelines (USA) mixed learning outcomes (or something similar) with other text, which describes future challenges or learning activities. For example (ref 12, p 14):

> *Solving scientific problems often involves multidisciplinary teams. The ability to work in such teams is essential for a well-educated scientist. Students should be able to work effectively in a group to solve scientific problems, be effective leaders as well as effective team members, and interact productively with a diverse group of peers. Programs should incorporate team experiences in classroom and laboratory components of the chemistry curriculum.*

In the Australian standards, the learning outcomes were clearly stated as "Threshold Learning Outcome Statements", while for the Eurobachelor they were formulated as aspirations such as "[t]he main abilities and competences that students *are expected to have developed*" (emphasis added). The learning outcomes in the Eurobachelor were also somewhat more detailed than in the other documents. Such differences might be of importance for the level of expectations for student achievement in relation to assessment.

As the learning outcomes were categorized according to different schemes in the various overarching documents, a unified scheme was created based on these different documents in order to allow for a more structured comparison of the learning outcomes across the overarching documents. The categories were the following: *Scientific skills*, *Laboratory skills*, *Chemical literature and literacy skills*, *Communication and interaction skills* and *Personal and social responsibility*. When sorted in similar categories it was clear that by and large the same competencies are found in the three documents. However, there were some notable differences.

All documents emphasized "scientific skills". Defining and formulating problems received greater emphasis in the documents from the USA and Australia, where students were supposed to be able to "define problems clearly" and formulate "hypotheses, proposals and predictions". The Eurobachelor focused on problem solving and analysis.

Laboratory skills were important in all documents. The Eurobachelor had a more elaborated text regarding laboratory

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skills and mentioned e.g. "instrumentation in synthetic and analytical work, in relation to both organic and inorganic systems" and "monitoring, by observation and measurement, of chemical properties, events or changes, and the systematic and reliable recording and documentation thereof."

The ACS guidelines (USA) had, on the other hand, the broadest perspective on lab safety, urging the students to be proactive and "minimize potential chemical and physical hazards in the laboratory, and know how to handle laboratory emergencies effectively".

All documents valued students' capacity to search for, handle and interpret information from various sources. The ACS guidelines and the Eurobachelor both indicated the importance of scientific literature ("peer reviewed scientific literature" and "primary··· information sources" respectively), while the LTAS from Australia emphasized "synthesizing and evaluating information from a range of sources". The emphasis on information retrieval and management skills was however stronger in the ACS guidelines and Eurobachlor compared to the Australian LTAS.

Communication and interaction were seen as important areas. The LTAS from Australia had the strongest requirements for varied communication and expected students to "communicate chemical knowledge by presenting information, articulating arguments and conclusions, in a variety of modes, to diverse audiences, and for a range of purposes." Foreign language skills were only suggested in the documents from the USA and Europe. While all the documents mentioned the importance of teamwork, the ACS guidelines mentioned in addition effective leadership as an outcome.

All documents included parts that point to the importance of chemistry bachelors not only having subject knowledge and practical skills, but also being able to take responsibility. This was most briefly mentioned in the Eurobachelor, where "Ethical commitment" was listed as a general competence, and most thoroughly described in the LTAS from Australia, where students were supposed to, e.g., "take personal, professional and social responsibility" and recognize "the relevant and required ethical conduct and behavior within which chemistry is practiced". Furthermore, in both the ACS guidelines and the LTAS, the place and role of chemistry in a global perspective was also raised as an outcome. In the documents from Australia and Europe self-directed learning and capacity to adapt to new situations were also included. An important aspect that arose during discussions was how to anticipate trends and future needs in chemistry education, such as an increased emphasis on sustainability, and how these can be met by new and evolving curricula.

The three overarching documents together gave perspectives on chemistry education, and were thought to be of value for local discussions on the chemistry bachelor. However, the documents were limited to the Euro-American-Australian world. Discussions about important issues for rapidly growing economies and developing countries are needed, in order to see the extent to which the assembly of competencies needs to be refined and adapted. We do not strive for a worldwide consensus, but rather global understanding and awareness of thoughtful differences.

■ LEARNING OUTCOMES ACROSS LEVELS FOR CHEMISTRY BACHELOR

As mentioned earlier, the tool for self-analysis that was created and developed prior to and refined during the workshops also enables comparisons both across and within educational systems (Supporting Information). In the same way that broad agreement was found across educational systems at the level of the overarching descriptors (level 1), there was also a high level of agreement between the various bachelor programs (level 2). In addition, within-system comparison across the levels also showed good agreement between the level 1 and level 2 documents. At the same time the tool for self-analysis was valuable for identification of blind spots and reflections on emphasis and expression.

By continuing the analysis of the institutional (level 2) and course level documents (level 3), the tool provides a way to capture an overview of the relevant learning outcomes in a thematic fashion, right across all levels of documents. At the course level, an important feature is that the concept of constructive alignment is built into the tool, in the table dealing with course-level learning outcomes. By requiring the user to explicitly identify learning activities and assessments correlated to each of the learning outcomes, the analysis is extended beyond what learning outcomes are found in the syllabi to *how* students are able to achieve them with the help of learning activities. Similarly, the inclusion of assessment reveals *how* students are able to demonstrate their achievements. Discussion and appraisal of the appropriateness of learning activities and assessments for each learning outcome are facilitated, and gaps in direct learning activities and assessments can be identified. This requires a level of knowledge of the actual delivery and teaching of the courses, and as discussed further below, the individual professional insight of the user of the tool is crucial for this layer of analysis.

With the use of the self-analysis tool as an aid, a selection of course syllabi from the participants' home institutions were analyzed, representing a mixture of American, European, and Australian universities. This revealed issues in terms of certain learning outcomes that were missing or treated inconsistently across the documents at the different levels. Typical areas where this was observed across the various institutions are chemical literature skills and teamwork, as well as those involving judgment, ethics and metacognitive skills. An example is learning outcomes at level 2 where students should demonstrate the higher-order skill of making assessments in chemistry informed by relevant disciplinary, social and ethical issues and demonstrate insight into the role of knowledge in society and the responsibility of the individual for how it is used, while the learning outcomes at level 3 mostly concern the lower-order skills of giving descriptions and examples.

An important aspect during this part of the process is that, in addition to analyzing the wording of the documents, the workshop participants could bring their personal knowledge about how these documents are interpreted and applied in practice at their own institutions. Discussions of these issues gave insights into different values and views of these documents. For example, learning outcomes in the Swedish national criteria for the bachelor program (level 2) and course syllabi at individual institutions (level 3) strictly speaking have legal effect, in that the university certifies that a student who has passed a course has demonstrated their achieving all the learning outcomes. Such a legal dimension is, however, not generally applicable in other educational systems. There is therefore a contrast in the role of learning outcomes, between being the basis for a legal certification on the one hand, and objectives of a more aspirational or guiding nature on the other. This places restrictions on how the learning outcomes can be

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formulated. Indeed, learning outcomes were not necessarily explicitly included in each and every course syllabus in all countries. Even at the less formal level, the discussions that are an integral part of this analysis process allow participants to share and discuss their experiences as to how and to what extent the syllabi are applied.

As found, e.g., by Wieman et al.[15] the development of intended learning outcomes (or learning goals) is a great challenge and a large part of the education transformation process. Therefore, the workshop format with the many possibilities for various comparisons was found to be fruitful. The process allowed productive discussions about both explicit and implicit differences between the documents from the various education systems and institutions. The explicit differences were those that the participants were aware of from the start, involving conscious choices that had been made, often taking local needs into consideration. The above mentioned restrictions placed by the legal dimension of the learning outcomes in Sweden is one such example. By contrast, implicit differences became apparent during the discussions, and these were also areas where changes were more often called for as a result of the discussions.

Exploring learning outcomes at course level also made it clear that progression throughout the degree program could sometimes be enhanced. Communication was such an area, where the same types of learning outcomes were seen to be repeated throughout courses, with little obvious progression in the expected levels of achievement. An example of a learning outcome from one university with similar wording through many courses was "keep running records of laboratory work, and account for contents and results of laboratory exercises both orally and in writing."

Formulation of learning outcomes is, however, just the first step. They will have limited practical value if they are not constructively aligned with learning activities and assessment.[1] Students will not fulfill the learning goals without possibilities to learn and practice through appropriate learning activities, and they will not take the learning outcomes seriously, if the teachers do not value them in assessments. The tool therefore also includes possibilities for self-analysis of learning activities and assessment.

The process of performing the self-analysis on the selected courses also unveiled some deficiencies in assessment. This was especially true for learning outcomes concerning generic and "soft" skills such as communication, literacy and ethics. Even when these competencies were addressed, they were rarely assessed. Here, the first-hand knowledge and insights of the participants about the implementations of their courses again came to the fore. Such direct insight was particularly useful for analyzing assessments, as this was often where the course syllabi were most brief (e.g., "Written examination", "Laboratory exercise"). The interactions and discussions between participants were critical for taking the process beyond just the wording of the documents, to evaluating the practical realities in actual teaching situations. While assessments and learning activities vary widely and are therefore more difficult to compare and discuss, much was learned from sharing insights and discussing possibilities.

■ IMPLICATIONS FOR CHEMISTRY EDUCATORS

A way for improving chemistry education is to engage in discussions on the most important skills and competencies for students to acquire and to let those direct the improvement of intended learning outcomes, learning activities and assessment in courses or modules. This is done by many university teachers across the world. A problem is that many reinvent the wheel, without taking advantage of the work that has already been done by others in developing effective curricula. On the other hand, it can be problematic if the work of others were adopted without taking into account local considerations.

We offer here a process-focused method for analysis and development of chemistry education programs that is especially designed to enhance comparisons between institutions, with a heavy emphasis on discussion and critical reflection. A tool for self-analysis has been developed that can be used to support this process. As far as we are aware, this process described here is a novel approach and framework for tackling and understanding the relationships between learning outcomes at different levels across institutional and national boundaries. It differs from other efforts that have been made to distill out documentations of a prescriptive nature, of which the level 1 documents examined here are examples, as well as other projects such as the CDIO initiative for engineering education.[16] Rather than adding to the myriad of rules and guidelines, we aim to assist the chemistry educator to navigate through those that exist and use them for quality enhancement of their courses and education programs.

As pointed out earlier, the value of the process of analysis should not be underestimated, which is why the tool developed in this project would be best used in conjunction with discussions, either among colleagues from the same institution, from other institutions, and/or various stakeholders including current and former students. These discussions would also help to identify current and future students' needs, and adaptations that may be necessary to deal with constraints or opportunities at hand.

At the 23rd IUPAC International Conference on Chemical Education 2014 in Toronto, Canada, several project members held an open workshop on the process described here. The utility of the tool could be tested and demonstrated among university faculty who had not been part of the project. In addition to lively and productive discussions, the workshop leaders observed that the use of the process and the tool for self-analysis enabled the workshop participants to lift the discussion about learning outcomes at different levels to a higher level of abstraction. Instead of just focusing on the presence (or otherwise) of individual skills and content knowledge in a piecemeal fashion, the discussion-orientated process, coupled with the tool for self-analysis, turned the mind toward more general and holistic considerations. Examples include the competences expected of a chemistry graduate, progression throughout the degree program, the formulations of learning outcomes, higher order thinking skills (e.g., not just what content knowledge is included), and connections from the course level right up to the national/international level. At the same time, specifics such as the learning activities actually employed, details of assessments to examine achievement of learning outcomes still had a place in the discussions. Feedback from the participants was very positive, and participants commented that the tool could readily be used to support reflection and insight in chemistry programs, supporting the development of strategies for improving chemistry programs in their own institutional contexts. This was good indication of the usefulness and cross-institutional transferability of the process for the purpose of quality enhancement.

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CONCLUSIONS

A clear outcome of this project is that the insight gained during the very process of analysis and critical comparison is as important as the resulting list of similarities and differences. The process enhanced the participants' awareness of the course and program curricula in a much broader context than expected, and highlighted blind-spots and less obvious areas that require improvement. We conclude that the method has promising features that can be used not only to compare different educational system, but also applied to a particular system, elucidating the correspondence between learning outcomes at different levels, and the constructive alignment between learning outcomes, learning activities and assessment. Beyond quality assurance, which focuses on looking at the existing structure, this process has the possibility of quality enhancement of education programs. This approach looks ahead and anticipates new trends, which is of importance for the process to improve chemistry education.

The international discussions and critical comparison facilitate insights into local bachelor programs and open perspectives of new possibilities. There is a need for collegial discussions of the purpose and goals of chemistry education and the described method can be a means to this. In considering "best-practices" in chemistry education, respect for various needs and possibilities for students at different universities is needed. Such a comparative approach without presupposing a "gold standard" in any particular system is consistent with this objective.

As chemistry bachelor degrees from abroad are often accepted for fulfilling entry requirements into master programs, there may be arguments for establishing prescriptive worldwide standards. However, we do not think that such an approach would be beneficial. Instead the chemistry community needs to recognize various ways of designing educational programs. The enhanced awareness, promoted by the discussions using the methods described, could lead to harmonization without unnecessarily limiting constraints. For this to be done, a tool where not just one, but several frameworks are readily available and contrasted with each other is valuable.

ASSOCIATED CONTENT

Supporting Information

The comparison between the overarching documents, i.e., the ACS guidelines, the Eurobachelor and the Learning and Teaching Academic Standards from Australia. The tool for self-analysis, in which (1) local learning outcomes at degree program curriculum can be compared with the overarching documents, (2) learning outcomes for courses or modules can be related to the each other and learning outcomes at degree program curriculum, and (3) the constructive alignment between learning outcomes, learning activities and assessment can be investigated. This material is available via the Internet at http://pubs.acs.org.

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Notes

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