Didaktik Models in Chemistry Education
Jesper Sjöström,* Ingo Elks, and Vicente Talanquer

ABSTRACT: The decisions and actions that chemistry educators make regarding why, what, how, and when to teach certain content or implement a specific instructional activity are often guided, but also constrained, by explicit or implicit “didaktik models”. These types of models direct our attention and actions when designing curricula, planning for instruction, or assessing the learning process. They also give educators a professional language when talking or reflecting about teaching and learning. When used systematically, didaktik models support the implementation of research-based instructional practices and are helpful in the professional development of educators. In this essay, we describe, analyze, and discuss the nature and utility of didaktik models in chemistry education and argue that it is critical for chemistry educators to recognize and reflect on the types of models that guide their work.

KEYWORDS: Curriculum, History/Philosophy, Professional Development

INTRODUCTION
Educators throughout history have generated models that seek to identify and characterize important elements of teaching and learning at general and domain-specific levels. These models direct our attention to critical components and processes that need to be understood, critically analyzed, or taken into consideration when designing curricula, planning for instruction, or assessing educational practices. We refer to these types of models as “didaktik models” in this paper, where we analyze and discuss the nature and value of these educational tools for chemistry educators and describe different types of didaktik models for chemistry education. Didaktik models are often used in implicit manners by chemistry educators, and we seek to make them more explicit to facilitate the recognition of the thinking and practices that they support, and to spark reflection on their potential limitations and the constraints they may impose on teaching and learning.

THE DIDAKTIK TRADITION
The concept of didaktik was coined in Germany during the early 17th century on the basis of a linguistic connection to the Greek word for teaching, didaskein. At the end of the 18th century, the term spread to countries that had close connections with German-speaking cultures, mainly the Scandinavian countries (Denmark, Norway, and Sweden). Nowadays, the humanistic didaktik tradition is fairly strong especially in central and northern Europe, where it refers to both the art of teaching and the professional scholarship of teaching.1–6 Although this tradition did not take hold in English-speaking countries, where the term “didactic” (spelled with “c”) often stands for behaving like a conventional teacher who delivers content knowledge through lecturing, the term “didaktik” (spelled with “k”) is increasingly being used in the international education literature, and also “didactic” (spelled with “c”), with a meaning given to that in continental Europe.1–12

In the beginning of the 19th century, Johann Friedrich Herbart (1776–1841) highlighted practical philosophy and psychology as the two main legs of didaktik. Practical philosophy gives direction when it comes to the goals of education (why-questions), while psychology points to effective ways and means for teaching practice (how-questions). The psychological component of Herbart’s ideas has been dominant in educational work in the US, while the connection to practical philosophy has remained relatively strong in northern Europe.4,10 After World War II, the field of instructional design12 was developed in the US in parallel with further developments of didaktik in Europe by Paul Heimann (1901–1967) and Wolfgang Klafki (1927–2016), among others. Instructional design has traditionally focused on teaching methods (how-questions), while European didaktik has been more content and relevance focused (what-and why-questions). Nevertheless, both orientations are important when thinking about and reflecting on education in any given area.

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In the humanistic didaktik tradition, there is a strong connection between the concepts of didaktik and Bildung. According to Duit (p 325), didaktik "stands for a multifaceted view of planning and instruction; it is based on the German concept of Bildung." Bildung refers to the knowledge- and values-formation of a person in interaction with its surrounding society. The rich and multifaceted nature of humanistic didaktik is the critical reason why in this paper we use the term "didaktik models" (spelled with "k") to refer to education-oriented models that support educators’ thinking and action inside and outside the classroom, independent of whether they were developed within the European or the American traditions.

### DIDAKTIK MODELS

The central aim of didaktik models in education is to guide teacher thinking when making educational decisions, before, during, and after teaching practice. Didaktik models can be used in the design, implementation, and analysis of curriculum and instruction, as well as for critical reflection on different educational approaches, prevalent practices, or teaching dilemmas. Furthermore, they give teachers a professional language that can be used to more effectively communicate goals and experiences when talking about teaching and learning. They strengthen teachers' agency by providing new perspectives and insights into educational ideas and practices. Didaktik models also can guide teacher education and continuing professional development and provide support in the implementation of research-based instruction. Some didaktik models can serve as planning and design tools, while others provide a basis for educational action (i.e., teaching practice). Some of them work primarily as analytical and evaluative tools, aiding teachers in the selection of content or orientation to teaching. There are also models that can be thought of as "metamodels", highlighting for instance connections between theoretical views (e.g., philosophical, sociological) and teaching practice. Some examples of these different types of didaktik models are presented in the next section.

Many didaktik models offer direct educational guidance on matters related to

- relevance (helping to address why-questions)
- content (helping to address what-questions)
- practice (helping to address how-questions)
- sequencing (helping to address when-questions)

Didaktik models for practice tend to be more widely known as they are applied across disciplinary boundaries. For example, didaktik models such as the Karplus learning cycle (exploration → concept invention → concept application) and the 5E instructional model (engagement → exploration → explanation → extension → evaluation) provide specific road maps for teaching practice. Other examples in this category include models for lesson planning and for more actively engaging students in the classroom, such as the predict–observe–explain (POE) strategy.

Other types of didaktik models identify and characterize major educational actors and the factors that affect their behaviors and interactions. These types of models facilitate and guide analysis and reflection about educational structures and processes. Consider, for example, the Berliner didaktik model developed during the 1960s, which highlights decisions and conditions affecting teaching (Table 1). This model includes six core elements, four of them under a teacher’s decision field and two in a teaching conditions field.

### Table 1. Berliner Didaktik Model

| Teacher’s decision field | Teaching intentions (why-questions) |
|--------------------------|-------------------------------------|
| Subject content/themes (what-questions) | Methodology (how- and when-questions) |
| Media choices | Student (anthropogenic) conditions |
| Sociocultural context |

In a similar direction, the didaktik model depicted in Figure 1 foregrounds three main educational actors (teacher, student, and content), depicted at the corners of the classical didaktik triangle, advanced in the late 19th century, but with roots back to John Amos Comenius (1592–1670), the father of didaktik. The expanded version of the triangle in Figure 1 highlights the different contexts to be considered and questions to be answered in the design, implementation, analysis, and reflection of instruction. Other expanded versions of this triangle have been described in more detail in, e.g., ref (pp 18–19).

### DIDAKTIK MODELS IN CHEMISTRY EDUCATION

Different didaktik models, although seldom called so, have been advanced in chemistry education to guide curriculum design and lesson planning, implementation, and assessment. Many of these models can be subdivided into the following categories, although the borders between them are not sharp:

- Content models
- Relevance models
- Sequence models
- Practice models
- Curriculum models
- Analysis and reflection models

In the following paragraphs we describe and discuss some examples in each group. We selected didaktik models described and discussed in the chemistry education literature that (a) were judged by us to be representative within each category and (b)
emerged from different educational traditions (e.g., European, American, etc.).

### Content Models

These types of models provide a framework for the organization of subject matter knowledge in a discipline (what-questions). Perhaps the most well-known and influential content model in chemistry education is Johnstone’s triangle (or the chemistry triplet), which highlights three levels at which the teaching and learning of chemistry operates: the macroscopic, submicroscopic, and symbolic levels. Although this model has been reinterpreted in diverse ways, it has been mostly used to characterize the types of chemical knowledge (what-questions) that students must develop to meaningfully understand chemistry. The chemistry triplet illustrates the power of didaktik models that can shape curricular decisions about what is taught as well as teaching choices about what is emphasized in chemistry courses (e.g., building connections between symbolic representations and particulate models of matter).

The chemistry triplet is a rather general content model that characterizes different types of chemical knowledge that students are expected to learn. In contrast, the Anchoring Concept Content Map developed by the ACS Exam Institute represents a quite detailed didaktik model in which the content to be taught and learned is specified at four different levels of granularity: anchoring concepts, enduring understandings, subdisciplinary articulations, and content details. The specificity of this model makes it useful in the design of standardized assessments and in the programmatic evaluation of curricula.

### Relevance Models

Some didaktik models help guide reflection on the aims and purposes of education (why-questions). For example, Johnstone’s triangle has been expanded by different authors into models that highlight different aspects of purpose and relevance in chemistry education. In this direction, Mahaffy proposed to transform the triangle into a tetrahedron by adding the human element, including relevant contexts of application and productive practices in the discipline (Figure 2a). Later, Sjöström suggested that this tetrahedron could be enriched by recognizing different levels of complexity in the analysis of humanistic aspects in chemistry education. These levels are represented as different layers of the tetrahedron, when moving from the disciplinary bottom triangle toward the humanistic apex (Figure 2b). More recently, Sjöström and Eilks have discussed that the different levels of complexity in the humanistic tetrahedron point to different answers to why-questions in chemistry education and to different visions of scientific literacy (Figure 2c). At the lower level, the emphasis is on the acquisition of chemistry knowledge and practices for later application; at the second level, the focus is on understanding the utility of chemical knowledge in daily life and society, while at the third level the intent is to promote the development of critical chemical thinking for sustainable action and socio-ecojustice. These three levels are connected to visions I, II, and III, respectively. Visions I and II of scientific literacy were first described by Roberts: Vision I starts from and focuses on the scientific content and scientific processes to be learned to understand important applications, while vision II...
focuses on contextualizing scientific knowledge to give it meaning to the individuals and the societies they live in. Sjöström and Eilks have introduced vision III, which emphasizes philosophical values, global sustainability, and critical-reflexive Bildung.33

Sequence Models

Some didaktik models characterize how students’ understanding of a concept or idea often changes with conventional instruction (conceptual progression), or how such understanding could best evolve toward the desired target with instruction (learning progression).35 Conceptual progressions describe changes in the concepts that many learners apply when thinking about certain properties or phenomena. Learning progressions present research-based conjectures about the instructional sequence that best supports progress in student understanding from an initial level (lower anchor) to a desired level (upper anchor).36 Conceptual progressions help teachers formatively assess student understanding and guide student thinking in more productive directions. For example, existing educational research has been used to build a didaktik model for the evolution of students’ understanding of the particulate nature of matter.37 This model describes common stages in student thinking, from conceptualizing all matter as continuous, to thinking of particles as embedded in a continuous medium, to considering particles as small pieces of macroscopic matter, to visualizing the existence of distinct interacting particles. Such didaktik models facilitate the diagnosis of students’ ideas in the classroom and the selection of instructional interventions based on the results of those assessments.38

Science and chemistry education researchers have also developed didaktik models for how to best sequence instruction to scaffold the construction of chemical ideas. For example, learning progressions have been proposed for the teaching of the structure of matter,39 chemical change,40 and molecular structure and properties.41 Such models help teachers make informed instructional decisions and develop assessments that better measure student progress.

Practice Models

A wide variety of didaktik models for chemistry education (many of them published in this journal) represent ideas about how to teach a specific topic to foster student understanding. These types of models often encapsulate strategies to facilitate skill development, such as completing specialized numerical calculations (e.g., using mole ratio flowcharts to solve stoichiometry problems,42 using ICE tables to calculate equilibrium concentrations43), generating chemical representations (e.g., drawing Lewis Structures44), inferring implicit properties of chemical entities (e.g., determining oxidation states45), making predictions about the outcome of chemical changes (e.g., using a majority/minority to analyze chemical equilibrium systems46), or facilitating student construction of molecular level explanations (e.g., MORE thinking frame47). Many of these models include constraints in their range of application and thus should be used cautiously in instruction.

Another type of practice model can guide the orientation and degree of innovation practices in a certain field of chemistry education. For instance, Burmeister et al.48 have suggested a model of how to integrate chemistry education with education for sustainable development. They identified four domain types of increasing complexity: a technical domain (applying green chemistry practices in lab courses), a content domain (enriching the curriculum with sustainable chemistry content), a curriculum domain (teaching complex sustainability questions as socioscientific issues in chemistry education), and an institutional domain (making sustainable development the guiding principle of school development).

Curriculum Models

Another type of model is curriculum models that provide integrative frameworks for the teaching of a discipline (what? why? how? when?). An example of such a model for chemistry education based on socioscientific issues (SSI) is presented in Figure 3.49

The first pillar in Figure 3 highlights the central aims of SSI-based teaching (why?) with a focus on the development of scientific literacy and Bildung. The second pillar provides criteria for the selection of topics that guide instruction (what?) and evaluation of whether any topic is aligned with the teaching goals (why-questions). The third pillar provides guidance on how to make the teaching and learning relevant and therefore motivating to the learners (how?). Finally, the fourth pillar...
suggests a potential teaching sequence (when?). The proposed sequence emerged inductively through participatory action research projects involving chemistry teachers (e.g., biodiesel usage\textsuperscript{50} and musk fragrances in shower gels\textsuperscript{13}). This didaktik model has inspired research to explore, e.g., the relationship (analysis and re-models) but may also serve to promote critical reflection to the aims and purposes of chemistry education (relevance models),\textsuperscript{54,55} diverse conceptualizations of central ideas in chemistry,\textsuperscript{54,55} as well as analyses of pedagogical, sociological, historical, and philosophical facets of chemistry education that should be considered when designing curricula, planning instruction, or engaging in the professional development of teachers.\textsuperscript{52,58} Many of the didaktik models for analysis and reflection invite chemistry educators to transgress traditional visions of school chemistry,\textsuperscript{55,59} and to adopt a more sociocritical and corefexive position in the design and enactment of learning opportunities for all types of students.\textsuperscript{60}

### Analysis and Reflection Models

There is also a set of didaktik models generated by different educators that do not necessarily have direct utility in planning, instruction, or assessment but promote broad reflection about for example the aims of and approaches to chemistry education. Didaktik models in this category include, for instance, characterizations of different ways of reasoning in the discipline,\textsuperscript{56,57} diverse conceptualizations of central ideas in chemistry,\textsuperscript{56,57} as well as analyses of pedagogical, sociological, historical, and philosophical facets of chemistry education that should be considered when designing curricula, planning instruction, or engaging in the professional development of teachers.\textsuperscript{52,58} Many of the didaktik models for analysis and reflection invite chemistry educators to transgress traditional visions of school chemistry,\textsuperscript{55,59} and to adopt a more sociocritical and corefexive position in the design and enactment of learning opportunities for all types of students.\textsuperscript{60}

### FINAL COMMENTS

The boundaries between the different types of didaktik models presented in the previous section are not sharp. For example, the "triplet-based" models presented in Figure 2 direct our attention to the aims and purposes of chemistry education (relevance models) but may also serve to promote critical reflection (analysis and reflection models). Similarly, the model introduced by Burmeister et al.\textsuperscript{48} provides guidance for how to practically integrate sustainable development into chemistry education (practice model) while also pointing to important why-questions (relevance models). Nevertheless, the proposed categorization highlights major areas of teacher knowledge, thinking, and action that are influenced by these types of models. In explicit or implicit ways, didaktik models direct a teacher’s attention to relevant factors in the planning and implementation of instructional activities; they help instructors filter and process information in the classroom, and they guide the assessment of student learning. Didaktik models help teachers make educated decisions regarding why, what, how, and when to implement certain content or teaching activities, and they also guide educational research and development.

Although didaktik models are invaluable in the design, implementation, and analysis of curriculum and instruction, as well as for critical reflection on diverse educational issues, they may also constrain teacher thinking. Consider, for example, the practice model based on Le Chatelier’s principle commonly used to facilitate students’ predictions of the effects of different perturbations on chemical equilibrium. This model is used pervasively in chemistry textbooks and classrooms despite its known limitations and the student misconceptions that it often generates.\textsuperscript{51} Chemistry teachers could greatly benefit from engaging in critical reflection of the different types of didaktik models on which they rely, to better evaluate their strengths and weaknesses and more productively use them in planning, implementing, and assessing educational activities.

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**Notes**

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