CHAPTER 1

Engaging Learners with Chemistry: How Can We Better Understand and Design Supporting Structures and Programs?

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1.1 Introduction

Many projects that focus on fostering student engagement have been initiated and developed in different parts of the world. Some build on theoretical models and research findings explicitly; others have been designed based on practical experiences. Many have been state-driven or third-party funded, *e.g.* by industry or foundations that support STEM education developments (see chapters in this book).

Evaluation and research have accompanied several projects, though with different connections to theory and also with different foci, *e.g.* on teachers'

Advances in Chemistry Education Series No. 5
Engaging Learners with Chemistry: Projects to Stimulate Interest and Participation
Edited by Ilka Parchmann, Shirley Simon and Jan Apotheker

Published by the Royal Society of Chemistry, www.rsc.org

roles, student outcomes or implementation processes (see chapters of this book). Models of characterisation for 'engagement' make statements about what influences engagement (*e.g.* relevance, Stuckey *et al.*, 2013), how it can be fostered (see chapters of this book) and better understood (*e.g.* by mapping processes of interaction between variables, *e.g.* Urhahne *et al.*, 2012; Höffler *et al.*, 2017, both with regard to perceived support and success in student competitions).

With regard to transfer and changes in practice, especially those that aim to be long-lasting, hurdles still seem to be so high that changes are not sustained. When funding has ended it is more common that projects themselves come to an end, rather than lead to structures that enable them to be sustained in some way.

In summary, the current state of understanding and strengthening of engagement with science, or chemistry in particular, is still diverse as projects have different backgrounds, draw or build on different models and only seldom adopt holistic approaches, starting from theory and findings, linking those to specific goals and approaches, and investigating processes and outcomes with feedback loops on the design and implementation as well as on the roles of stakeholders like teachers or curriculum developers.

Hence, the claim for this book and elsewhere is that sustainable changes need holistic approaches and an involvement of different actors and processes right from the beginning, comparable to an 'educational ecosystem' with different niches, layered structures and iterative processes. This requires an analysis of the different structures and niches of today and future potentials, of the roles of the participating actors and of stimulating and hindering factors (like catalysts) and processes.

The models discussed in this chapter and the studies and approaches connected in this book focus on different aspects of such systems, including:

- *Engagement*: What do we mean with regard to different perspectives of interaction between individuals, science and society?
- *Interaction models*: How can we describe prerequisites, factors of influence and interaction processes on decision-making processes of actors of todays' and future STEM education?
- *Learning environments*: How can we implement these models into the design and investigation of learning environments, teaching scenarios and learning processes, how can we motivate and activate students?
- *Key players and stakeholders*: Who could and should be involved at which stage and in which role, like teachers, industrial members of the society, or politicians?
- *Outcomes for science and chemistry in particular*: Where do we identify the most crucial demands and how can we address these successfully by promising approaches?

In the following paragraphs, key models and perspectives will be explored to lay a foundation for the specific approaches and research findings of the different chapters, with regard to school and out-of-school learning in different countries.

1.2 Engagement in Science and the Specific Niche of Chemistry—Still a Challenge

Do we raise interest and engagement sufficiently in chemistry and science? The ROSE report in particular painted a bleak picture of science education. While students are concerned about the environment and climate *etc.*, science education did not seem to be very interesting, and is not seen as a means to work on these problems. Engaging students therefore has been and still is one of the major concerns in education (Sjøberg and Schreiner, 2010).

Indeed, science and chemistry in particular are related to different and partly non-coherent, if not even opposing interests and attitudes. In school, chemistry is viewed as fun and enjoyable with regard to watching or carrying out experiments, the latter related to positive attitudes (Hofstein, 2004). However, when it comes to theoretical interpretations, mathematical models and lab reports, this enjoyment might not always persist and the interplay between enjoyment, interest and learning is diverse with regard to such different scientific activities (Höft *et al.*, 2019). Public audiences enjoy 'science shows' with regard to edutainment, but not as a focus point for someone's own engagement, also often not with regard to fostering a career option, especially of daughters or granddaughters. In addition, girls often underestimate their self-concept and self-efficacy with regard to the abilities they actually have, and they still experience stereotype threats like 'hard sciences are for boys' (Höffler *et al.*, 2017; Steegh *et al.*, 2019). Last but not least we all make use of chemical knowledge and all the products developed and designed based on that knowledge, but large groups of citizens still believe that chemistry is dangerous and should be avoided (Rocard *et al.*, 2007).

One reason for non-sufficient attitudes and engagement might be the nature of how science and especially chemistry is presented in media and also in school science. Chemists have for a long time been regarded and presented as male, working mostly in white lab coats and perhaps being less social and rather nerdish people (Schummer, 2006; Weingart, 2006). Reflections on dominant images now seem to show that chemists and chemistry are presented by perhaps new stereotypes, related to either what the public might think of, like 'magic liquids' or what industry might want to point out more, like female scientists (https://www.chemistryworld.com/opinion/chemistrys-image-problem/3008806.article). Even people having or aiming at successful careers in chemistry often seem to reflect on such influences of stereotypes (*e.g.* https://www.labmanager.com/leadership-and-staffing/scientist-stereotype-is-it-working-for-or-against-you-20514). Another issue is the perception of relevance, hazards and achievements. Industry is rather connected to causes of environmental hazards, while products based on achievements of chemistry are regarded as normal and not as breakthroughs for the life we live today in many countries. With regard to motivation, school chemistry is often narrowed to learning formulae and carrying out experiments for which the outcomes are already known (Hofstein, 2004). While real science is complex and diverse with regard to fields and activities, school sciences mainly addressed well experienced, cookbook-like and conventional activities while especially creative, social and enterprising perspectives are seldom addressed (Hofstein and Kind, 2012; see also chapter by Bennett *et al.* in this book). The endeavour of better understanding the world and becoming a member of such an endeavour for the future has hardly been pointed out for a long time (Gago *et al.*, 2004). In self tests for career orientation, like the test based on John Holland's RIASEC model, science is connected to only some of the list of facets, primarily to working with routine hands-on experiments (dimension 'realistic') and/or investigating new phenomena in academia (dimension 'investigative'). Other facets like being interested in social activities are opposing to the typical science activities in the model. To overcome such stereotypes and probably hindering images with regard to engagement, a new approach has adapted this model to facets of interest within the science domain. The goal here is not to classify domains in prototype dimensions, where scientists are related to interests in investigative and realistic activities and others like nurses are related to other dimensions like social. In this new model, relations for all dimensions are created to science fields, like working with students or supporting societal demands in the social dimension, or developing and products or patents, or starting an enterprise based on a scientific finding. The classification is based on todays' fields and activities of scientists and has been tested in school as well as in out-of-school learning settings (Stamer *et al.*, 2019; Höft *et al.*, 2019). Hence, this does not claim to actually measure peoples' preferred interests in general, but only within the domain of science. Findings show that especially talented students do indeed express combined interests in investigative, social and networking dimensions when set in a science context (Dierks *et al.*, 2016; Höffler *et al.*, 2019).

How can we bridge such gaps to overcome stereotypes and too narrow beliefs without losing the enjoyment of chemistry? How could we even make use of the enjoyment of chemistry to strengthen individual, societal and career engagement by pointing out that learning and better understanding chemistry and science is fun and stimulating in itself? Showcasing the role of science, and more particular chemistry in society could be one of the ways to stimulate interest in science (see the special issue of the *Journal of Chemistry Education*, December 10, 2019 **Volume 96**, Issue 12 Pages 2679–3044, 'Reimagining Chemistry Education: Systems Thinking and Green and Sustainable Chemistry', for example). This can be done through formal learning in schools as well as informal learning in, for example, science centres. A closer cooperation between formal and informal learning can be one of ways to achieve this (see chapters by Simon *et al.*, and Blonder *et al.* in this book).

School chemistry approaches, such as science–technology–society (STS), context-based learning (CBL) or socio-scientific issues (SSI) address these gaps with different emphases (see chapters by Bennett *et al.*, Herzog *et al.* and Apotheker in this book). CBL, for example, uses real-life–science or societal–contexts to develop both a conceptual understanding and a variety of competencies, aiming to foster scientific literacy as well as career perspectives. Accompanying research has shown effects especially on motivation (Sevian *et al.*, 2018), however, not yet longitudinally. Taking the small number of school lessons into account, the more general and stable perceptions of what science is and should be in and for a society, of what one is able do or not with regard to important activities and the underlying competencies and of how learning science can successfully lead to doing science can probably not be addressed and solved by school science initiatives only. A systemic connection of in-school learning and out-of-school learning seems to be much more promising in this regard.

Hence, looking at where we are and what we can still learn, the challenge is probably not to initiate again and again more programs but to better link the existing ones and to optimise effects based on research from science and science education. This book will highlight the different approaches, design criteria and outcomes of projects aiming at fostering engagement for chemistry and science from different countries and link them in the final chapter to form a more coherent picture of programs and measures. The underlying goals of the measures range from aiming to strengthen scientific literacy for future citizens, to raise career options and to lay a foundation for future learning and/or to enable individual connections between science and one's own life. The approaches sill seldom incorporate parents and peers, but more often politicians, researchers and members from industry, next to the students and (future) teachers. For quality control and on-going future developments, different monitoring and evaluation approaches and instruments are presented, such as interviews, questionnaires and classroom observations, *etc.*

To better understand the relevance and achievements of the different approaches, the term engagement and the underlying models on fostering engagement need to be explored further.

1.3 Engagement—Characterizing a Term to Better Address Measures

Student engagement in science can be conceptualised in different ways but can be considered to involve a behavioural component when students do a science-related activity, an emotional component as they become interested and a cognitive component when they are motivated to want to continue with science in higher education or as adult citizens (Hampden-Thompson and Bennett, 2013). Engagement can have several components and stimuli, such as commitment for something, identification with something, a perception of expectancy or personal value, and others. Connecting to personal concerns and interests of students can help stimulate them to take part in science education (see chapters by Broman and Apotheker in this book, for example).

The notion of engagement has close association with what we understand by 'relevance' in science education. The review by Stuckey *et al.* (2013) on the meaning of relevance and its implications included a view of relevance having three overlapping dimensions:

> 'The individual dimension: the relevance of science education for the individual encompasses matching the learners' curiosity and interests, providing students with necessary and useful skills for coping with their everyday lives today and in the future, and contributing to the development of intellectual skills.
>
> The societal dimension: the relevance of science education from the societal viewpoint focuses on preparation of pupils for self-determination and a responsibly led life in society by understanding the interdependence and interaction of science and society, developing skills for societal participation and competencies for contributing to society's sustainable development. The credibility and authority of science plays a major role.
>
> The vocational dimension: the relevance of science education in the vocational dimension is composed of offering orientation for future professions and careers, preparation for further academic or vocational training and opening up formal career chances (*e.g.* by having sufficient coursework and achievements to enter into any given higher education programme of study).' (Stuckey *et al.*, 2013, p. 18).

Adapting these ideas about relevance, we perceive the field and extent of engagement within the wider STEM domain to be highly diverse, embracing at least these three major perspectives:

- *Personal engagement*: Which role does science play in a person's daily life, *e.g.* daily life decisions or career choices, linked to the next two? How does school science point out this perspective, *e.g.* through CBL?
- *Societal engagement*: How does science form or support engagement for different communities? Which environments like clubs, student lab programs, science centres or citizen science projects exist in different countries? How are they made available for interested students and adults?
- *Professional engagement*: Which career options are strengthened in a society and promoted for individuals, *e.g.* by career orientation programs, career advice and others? How are they implemented in school and out-of-school programs? Which roles can chemical societies

and/or organisations like the European Chemical Industry Council (CEFIC) take?

These three perspectives represent and address different layers of an educational system, starting from an individual perspective and moving towards the next layers of personal environment, learning environment up to the governance level and back. For any successful program, different levels must be incorporated as they overlap with each other.

To address or to foster engagement on the personal level, variables such as motivation and interest, self-perception and literacy or abilities are important and need to be taken into consideration. Also values and expectations of success or failure influence the choice of activities and programs. Values are influenced by parents and peers but also by a society, considering male and female stereotypes for STEM fields, for example. The first level depends on individual learning opportunities like school and out-of-school environments or teachers. The governance level is perhaps the most difficult to address, as this often requires long-term and political interactions, both may contradict each other as politics often change or funding ends before a program is well implemented. The credibility/authority of science is also at stake here. People need to be able or to be empowered to make individual decisions about scientific matters, involving the authority of science. Discussions on social platforms with emotional rather than scientific arguments influence many people. The dropping degree of participation in vaccination programs is an example. Science education can take these discussions into the classroom and give them a more solid scientific setting.

Existing models can be used to describe the interplay between those levels and variables, such as expectancy-value-models. However, the aspects addressed often differ between projects, which makes it rather difficult to identify common and most important criteria. Systematic reviews or meta-analyses are one approach to overcome this challenge. Books and special issues in which the different projects address the same issues and present their (missing) empirical evidence are another.

1.4 How to Understand Personal Choices for or Against Engagement in Science?

Models helping to describe, analyse and thereby better understand processes and influences on personal choice combine factors of individual goals and values with expectations and environmental factors. Two well-established models are the *expectancy value model* (*e.g.* Figure 1.1) and the model for the *theory of reasoned action*, both with adaptations and further developments.

Such processes can and should also be influenced by school science. Teachers can either support or hinder further and future engagement in chemistry, similar to parents (*e.g.* Urhahne *et al.*, 2012), both by being a role model and by offering further insights into the fields and people in chemistry. The latter seems as important as the content, as students reflect their

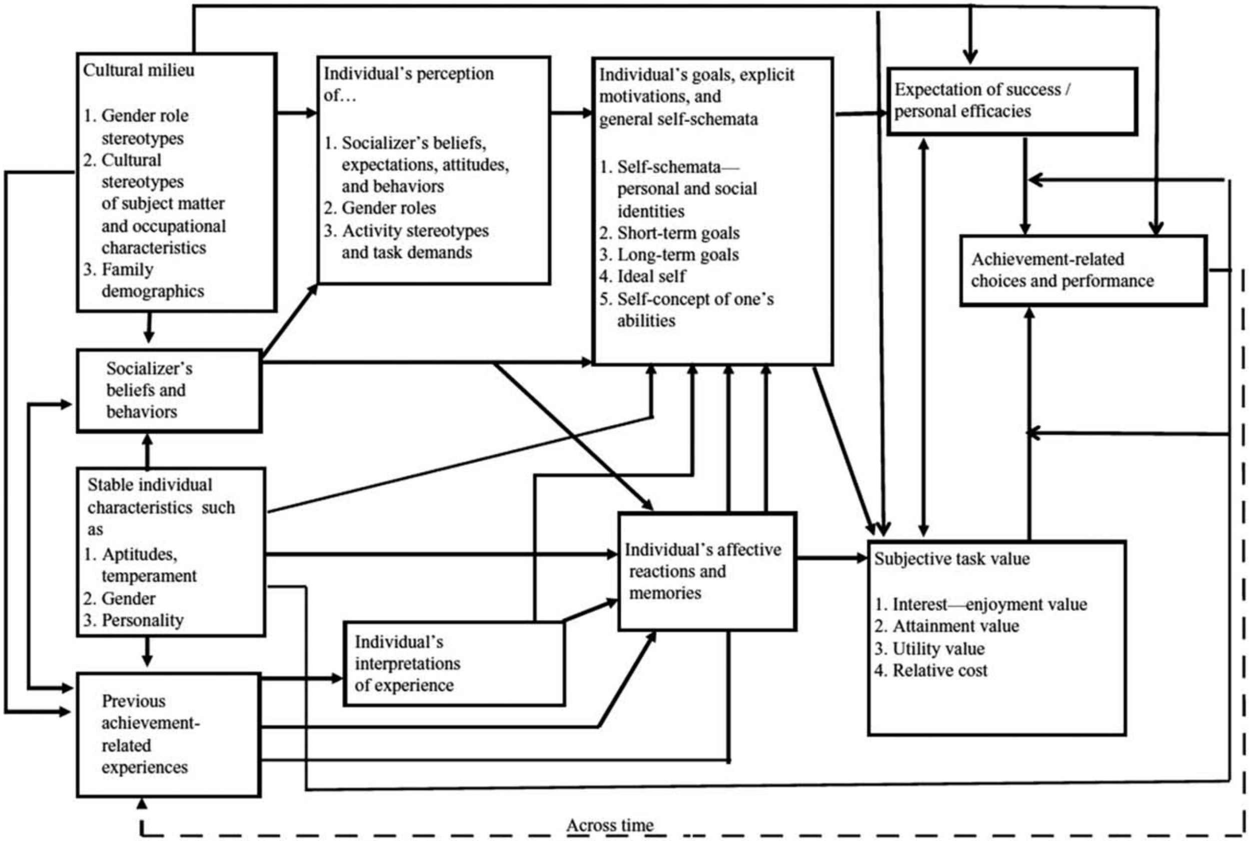

Figure 1.1 An exemplary expectance–value model from the project WinnerS, investigating students' participation and success in the German qualification for the Science Olympiads.

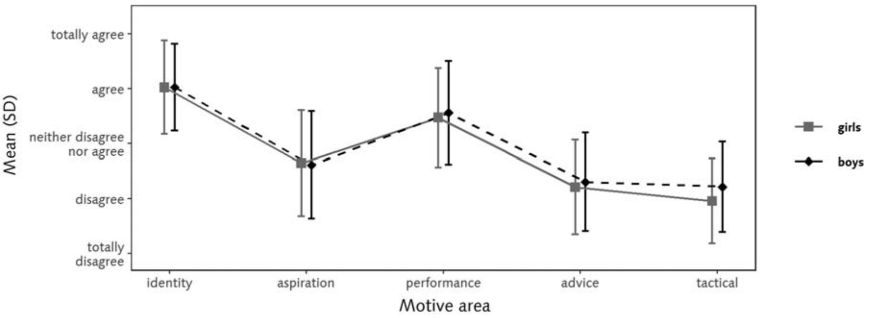

Figure 1.2 Influences on students' choices of school programs for upper secondary education in Northern Germany.

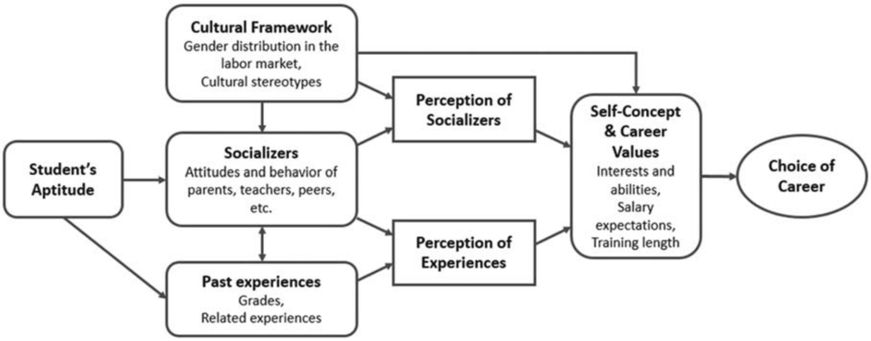

Figure 1.3 Model of career choice (Dick and Rallis, 1991).

self-perception now and with regard to future visions with the perception of scientists or chemists in particular (Hannover and Kessels, 2004). Also, chemistry education studies have shown the important influence of identity perceptions for the choice of school programs (Figure 1.2, Bernholt and Höft, 2017).

Hence, learning environments fostering on engagement should not only focus on interesting activities but also on future visions and scientists as persons. For specific situations, such as career orientation, other factors also come into play and require more differentiated and complex modelling processes, both with regard to theoretical assumptions and empirical studies. Herzog *et al.* describe and explore such a model for career choices, including cultural and social factors in addition to the students' own experiences (Figure 1.3).

1.5 How to Design Learning Environments, How to Investigate and Model Interactions?

Connecting individual pre-conditions and processes of choice and decision making with experiences like learning or exploring science requires connecting such individual factors with design elements of learning environments. *Utilization of learning opportunities models* by Helmke and others (Helmke, 2015) offer suitable frameworks for the design of both, environments and studies on processes and interaction, even though the complexity hardly allows for holistic studies. These models need to be enlarged for out-of-school learning (*e.g.* like in Figure 1.4) as students do not only interact with teachers but with real scientists, *e.g.* from research institutions or industry. These people are experts in their fields but do rather not have information or training on students' learning.

When learning environments are embedded in an educational ecosystem with their specific niche (see chapter by Corrigan and Smith in this book), like enrichment programs connected to school or out-of-school learning, they need to be designed in a way that connects the enjoyment of science with insights and explorations of what science actually is (the 'nature of science' in different contexts, see chapters on research links and chapters on industry links as well as the chapter on citizen science for science in society) and the learning of basic concepts, principles and skills.

As a connecting framework, linking science and society, the responsible research and innovation (RRI) framework highlights aspects of interfaces and interactions between science and society that can also be mirrored in activities (see chapter by Apotheker in this book). Also with regard to science literacy and so called 21st century skills (http://www.oecd.org/education/2030-project/teaching-and-learning/learning/learning-compass-2030/; https://www.oecd.org/education/2030-project/) students should get insights into how research works (what is scientific evidence, how can fake news and claims be distinguished from evidence?) and how it is connected to societal areas and decision making processes. This requires the design of suitable activities embedded in the learning environments, forming the linking elements between goals, interaction models and actual interactions and outcomes.

1.6 How to Design Activities?

A very common approach for science education, both in school and out-of-school is inquiry-based learning (see chapters from Bennett *et al.* and Apotheker, and Roennebeck *et al.*, 2016). The stages of inquiry mimic authentic activities of scientists, though often reduced with regard to complexity and less open. Out-of-school learning environments or visits by scientists offer more authentic explorations as they enable direct exchange, often more time and also equipment (see chapters by Hollweck and Schwarzer or Simon *et al.* in this book).

Science, however, does not only involve professional scientists anymore. The movement of *Citizen Science* aims to involve citizens in real science processes, like taking part in the collection or analysis of data on a large scale, *e.g.* for characterizing birds or insects. This approach has also been adapted for schools and school science, see the chapter by Kruse *et al.* in this book.

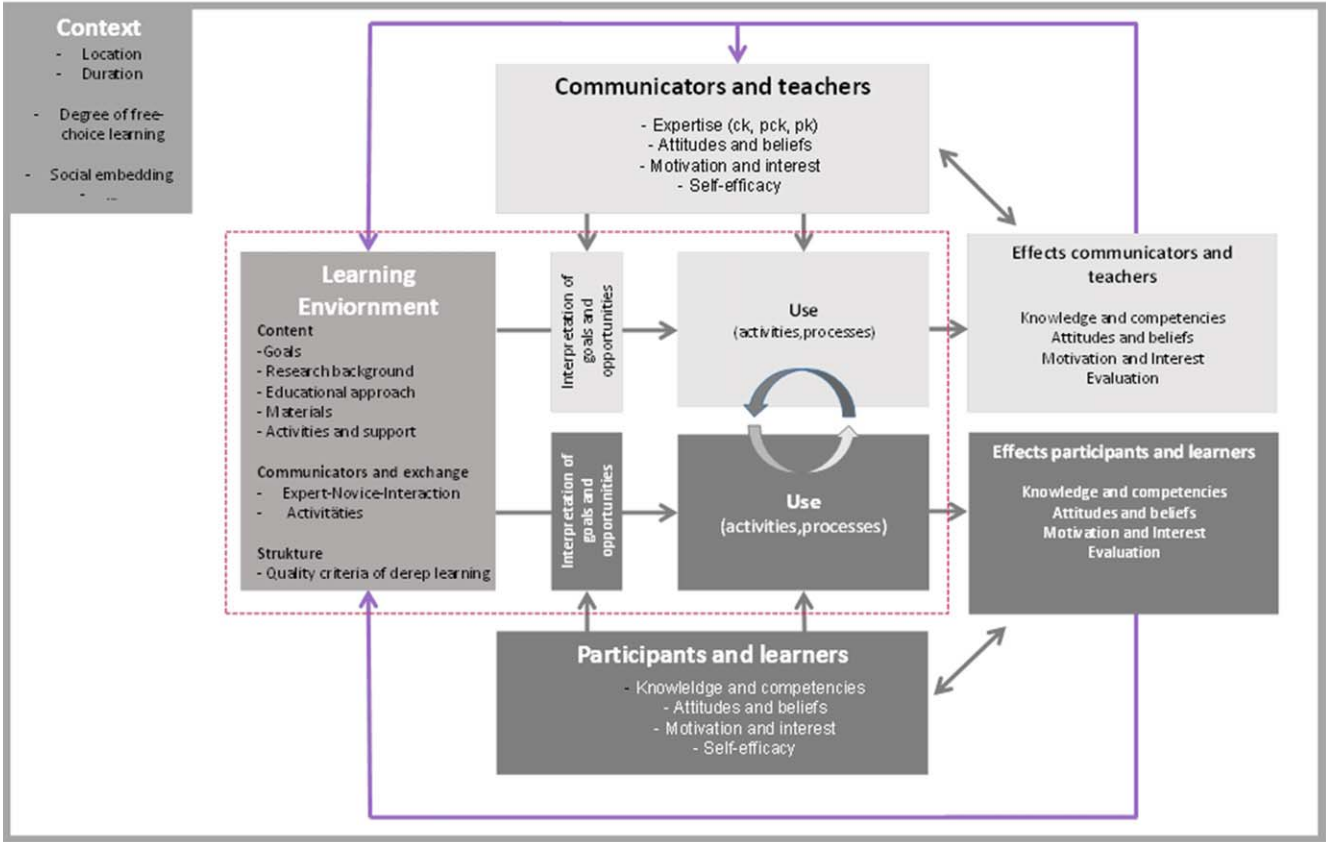

Figure 1.4 An adaption of a utilization of learning opportunities model for science education and communication environments.

Still inquiry, both in school or in citizen science projects, only shows one—though typical and important—feature of scientists' activities (see section above, *e.g.* Stamer *et al.*, 2019). Most programs reported in this book therefore incorporate other activities as well, like reading and communicating (even in different languages, see chapter by Hollweck and Schwarzer), presenting results to others (see chapters by Herzog *et al.* or Kruse *et al.*), visiting real science environments (*e.g.* chapter by Terada) or playing science theatre scenes (*e.g.* chapter by Simon *et al.*). The holistic picture of activities should be able to address different interests and thereby motivate more students for further engagement in science and chemistry.

1.7 Do Not Forget the Stakeholders: A Systems Thinking Perspective

Last but not least, learning environments based on theoretical models of choice and interaction and of content and authentic experiences must be implemented into an educational system. This requires and involvement of different actors and stakeholders, as described by Apotheker in his case study for the Netherlands. Digital options enlarge the picture globally, as explored by Corrigan and Smith. Models that can additionally be taken into consideration describe processes of implementation (see chapter by Apotheker) or even of cultural change, like digital transformations in education. Successful changes require implementation strategies, but also severe discussions of goals, norms and expected outcomes, as described in the *Concern Based Adoption Model*, for example (de Vocht and Laherto, 2017) or reflected in the chapters by Broman and Finlayson *et al.* when working with teachers.

The Storyline of the Book—Chapter Overview

The storyline of the book addresses and connects the different issues explored above in more detail. Starting with a chapter exploring design criteria for learning environments in general and with regard to the specific focus on inquiry, the next two chapters show how teachers can be involved in new approaches like CBL aiming to point out the relevance of chemistry in daily life and industry. Connections between schools, teacher training and industry are also in focus in the following two chapters, implementing such interactions strategically and systematically. Chapters 8 and 9 offer insights into environments and approaches for school students visiting research institutions. Chapter 11 forms links between scientists and school students through a citizen science program. Chapter 12 finally reflects on the involvement of stakeholders in change processes before Chapter 13 draws conclusions from all different perspectives (Table 1.1).

Table 1.1 Chapters in this book.

Chapter number	Authors	Title and main focus
1	Parchmann, Simon and Apotheker	**Engaging Learners with Chemistry: How Can We Better Understand and Design Supporting Structures and Programs?** Introduction overview about models and approaches.
2	Corrigan and Smith	**Complexity, Intellectual Challenge and Ongoing Support: Key Learning Conditions to Enhance Students' Engagement in STEM Education** Design criteria for engaging learning environments.
3	Bennett *et al.*	**Being a Scientist: The Role of Practical Research Projects in School Science** Engagement through inquiry.
4	Broman	**Engagement and Relevance Through Context-based, Everyday Life, Open-ended Chemistry Problems** Engagement through contexts, involvement of teachers.
5	Terada	**Development of a Context-based Learning Model Where Teachers Link Regional Companies and Science Classes Utilizing Relevance to Students** Engagement through contexts, involvement of industry.
6	Herzog *et al.*	**Cooperating with Companies Helps to Make Science Education More Relevant to School Students** Engagement through industrial contexts, involvement of teachers and companies.
7	Finlayson *et al.*	**Teaching and Learning Science from the Perspective of Industry Contexts** Engagement through authentic insights into industry in society, involvement of teachers and companies.
8	Blonder *et al.*	**Research Visits as Nuclei for Educational Programs** Engagement through authentic contexts, research visits.
9	Hollweck and Schwarzer	**Fostering Scientific Literacy with the Language of Science in the Production of a Nano-based After-sun Care Product in an Extracurricular Setting: A CLIL Approach in a Science Lab for School Students** Engagement through authentic contexts in research, role of language in science.
10	Simon *et al.*	**Enhancing School Students' Engagement in Chemistry Through a University-led Enrichment Programme** Engagement through cooperation, school visits to universities.
11	Kruse *et al.*	**Can Participation in a Citizen Science Project Empower Schoolchildren to Believe in Their Capacity to Act on Environmental Problems?** Engagement through cooperation between schools and science, students as citizen scientists.
12	Apotheker	**The Use of Contexts in Chemistry Education: A Reflection on System Levels and Stakeholder Involvement** Engagement through context-based learning, role of politics and stakeholders.
13	Simon, Parchmann and Apotheker	**Conclusions**

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