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ARTICLE

Modelling Authenticity in Science Education

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Abstract
The terms 'authenticity' and 'authentic' have been used increasingly frequently in educational contexts over the past decades. In science education, authenticity is claimed to be a crucial concept, inter alia, for students' motivation and interest in science. However, both terms are used, defined and conceptualised in various and ambiguous ways. So far, however, a model to integrate and structure the various conceptualisations, definitions and findings with their implementation in a teaching context is lacking. In this contribution, we introduce such a model, coherently integrating a broad range of work done by previous authors. Meanwhile, the model is flexible enough for future extensions and refinements. As many authors have shown, the concept of authenticity is multidimensional. In the present contribution, we therefore introduce a multidimensional model, explaining each dimension with reference to previous work on authenticity before integrating them as the complete model. We will outline a tool for practitioners and researchers which is based on the introduced model.

1 Introduction

> The term 'authentic' has become something of a buzzword in recent years when applied to educational interventions. It is applied loosely and inconsistently to a wide range of theoretical and practical work. (Shaffer & Resnick, 1999).

Authenticity[1] is a broad and complex concept used in multiple disciplines within education (Herrington & Herrington, 2006; Roth, 1995; Shaffer & Resnick, 1999) and well beyond (e.g. in arts and culture: Larsen (UNESCO), 1995, or in philosophy, Varga & Guignon, 2020). The term has seen increasing use in recent decades, in particular as related to education (see Fig. 1). The main purpose of the present contribution is to summarise authenticity as it is used in science education practice and research and to introduce a

[1] We follow the convention from linguistics to indicate the discussion of a term in italics (Bauer, 2007).

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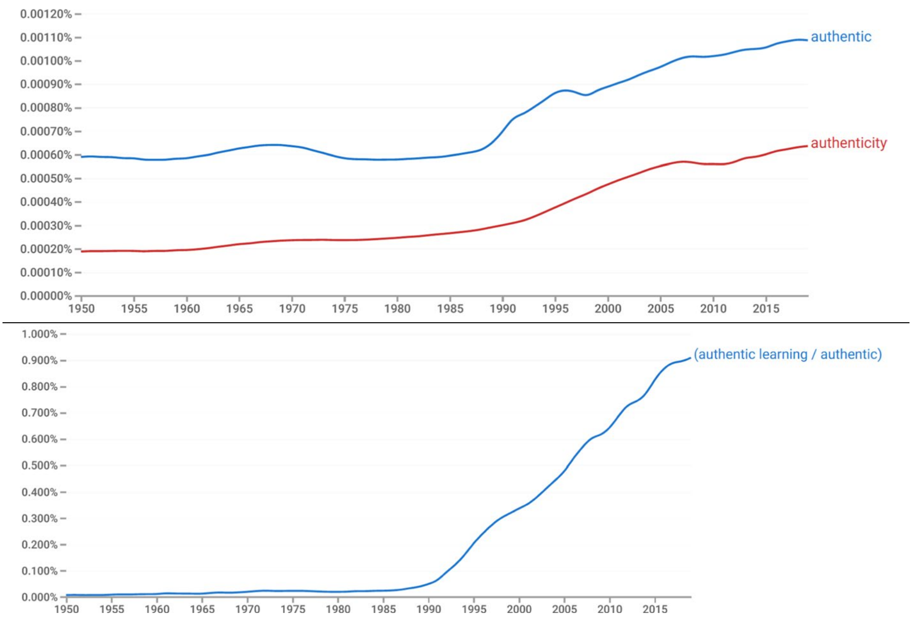


Fig. 1 Relative frequencies of use (occurrences) in English books since 1950 (Google, 2020; Michel et al., 2011); top, frequencies (%) of authentic and authenticity by year; bottom, ratio of frequencies of authentic learning and authentic by year. Taken together, these two diagrams show a moderate increase for the general use of authenticity, and a strong increase in an educational context

model encompassing a broad variety of meanings in a coherent way. Note that there are other perspectives of interest in other disciplines, in particular philosophy (Varga & Guignon, 2020), but also, for example, history, art and literature (Larsen (UNESCO), 1995), but these are beyond the scope of the present contribution.

The focus is on science education, but we refer to a broader theoretical background from different disciplines on which we base our model. In science education, authenticity is claimed to be a crucial concept to motivate students for science, to help them to connect scientific concepts and transfer knowledge to ‘real-world’ applications, and to achieve more positive attitudes towards science (D-EDK, 2017; King et al., 2008; National Research Council, 1996; Tytler, 2007; Weiss & Müller, 2015). For instance, Glowinski and Bayrhuber (2011) found out that ‘insight into authentic research’ was the most prominent predictor of students’ interest in authentic learning environments ($R^2 = 0.23$ to 0.24, $p < 0.05$). What does it mean for a student to be confronted with or to be immersed in an authentic research context? In the following, we try to define the framework of this multidimensional concept of authenticity.

Researchers complain that the term is ‘something of a buzzword’ and ‘applied loosely and inconsistently’ (see quote at the top of this section; Shaffer & Resnick, 1999). Indeed, as the detailed analysis in Section 3 shows, several conceptualisations are discrepant in the sense that they actually belong to different dimensions of usage and understanding.

Widespread use, on the one hand, and terminological and conceptual ambiguity, on the other, are not a good state of affairs for any scientific term. We agree with Shaffer and Resnick (1999) on the need for a more detailed analysis. The term *authenticity* has been discussed in several reviews and metastudies on which this article is based, suggesting the need for a unifying analysis.

1.1 Multidimensionality of Authenticity

A basic requirement for creating, evaluating and adapting 'authentic' learning situations and experiences is the concept of authenticity in science education. By first citing certain authors and conceptualisations, we illustrate the multidimensionality of the term 'authenticity'. We will explain crucial concepts in more detail later on.

For some authors, 'authenticity' or 'authentic learning' mirror the tasks or approaches of the experts in their professional field or which have a close relation to the 'real world' (Bennett et al., 2002; Braund & Reiss, 2006; Chinn & Malhotra, 2002; Honebein et al., 1993; Watkins et al., 2012). In their research, these authors focus on certain aspects of this 'real-world authenticity' such as 'authentic inquiry' or 'authenticity at out-of-school learning places' and not necessarily on the overall concept. So, there is not one, but rather a whole range of definitions of 'real-world authenticity'.

Petraglia (1998) claims that authenticity can only occur within the learner in interaction with a learning environment and describes the attempts to create learning environments corresponding to the 'real world' without regarding the leaners' perspective as 'preauthenticitation'. Hutchison (2008) suggests the term 'epistemological authenticity' as a conceptualisation after having comprehensively analysed the different definitions of authenticity in science education. With this concept, he connects disciplinary and personal authenticity.

Shaffer and Resnick (1999) stated that the term was used 'loosely and inconsistently' and they analysed the concept of authenticity specifically in science education. They identified four different 'kinds' of authenticity, which we will discuss in more detail later in this article.

All these different approaches (Bennett et al., 2007; Hede et al., 2014) show that the concept of authenticity is a multidimensional one and that any attempt to reduce it to a simple and one-dimensional definition would not be adequate. Within this empirical and theoretical framework, we postulate that a multidimensional model is needed to define and visualise the concept of authenticity in science education.

The model is addressed to researchers in science education and various kinds of instructors. An instructor can be a developer of teaching materials or a museum educator, but also a person working in industry or a science research institute responsible for visitor centres and public relations. All of them create, evaluate or investigate learning environments or opportunities for students or visitors.

The students or visitors are the actors in this model and are essential for its understanding: The experience of authenticity occurs within the student's or visitor's perception and is related to all the variables that influence personal perception, for example, their demographic and cultural background and their emotional involvement.

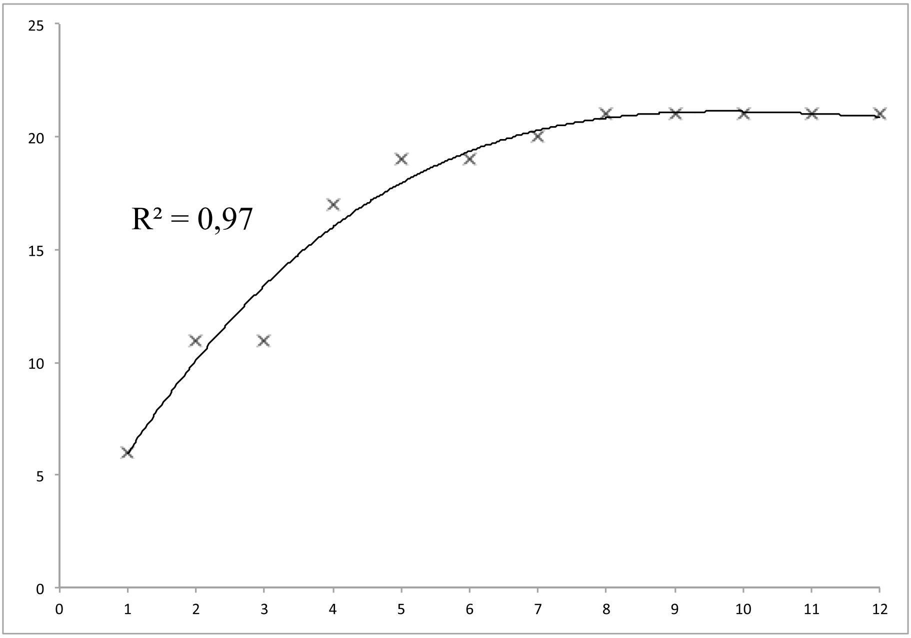


Fig. 2 Increase in the total number of conceptualisations of 'authenticity' in reviews (y-axis) as a function of the chronological order of the reviews (x-axis)

2 Theoretical and Methodological Approach

It is *not* our intention to add yet another conceptualisation or another term related to authenticity, but instead to distil this multidimensional concept in a model that might be useful for research and practice. We base our model on reviews, metastudies and articles that have dealt with this concept.

Our approach is inspired by the approach and visualisation of Labudde et al. (2005, 2012) on conceptual analysis and their synthesis model for cross-curricular/interdisciplinary science teaching. Based on its use in the literature, they show that 'interdisciplinary instruction' is a multidimensional concept and present a model structured by broad educational characteristics ('dimensions', for instance, 'content' and 'teaching methods') and specifications of these broader characteristics (referred to by them as 'facets', e.g., for the dimension 'content' contains the facets '(multi-)disciplinary orientation', 'complexity' and 'breadth'). Both 'dimensions' and 'facets' of this model are based on extant research and best practice.

Analogously, we present a conceptual analysis of uses and interpretations of 'authenticity' in the literature, a structuring of their variety based on research and best practice (in three levels: dimensions, subdimensions and aspects), and a visual model (with specific geometric properties conveying key features of the concept of authenticity. This work is about a *theoretical* approach for analysis and synthesis of conceptualisations of 'authenticity' in science education, but not a meta-analysis nor a systematic review of *empirical* work. Currently, there is no established way of applying the methodological tools for the latter type of study to the present paper. However, to go beyond the usual approaches for this kind of theoretical contribution, which—while providing useful and well thought-out analyses—are not based on a sufficiently systematic method to ensure enough coverage (e.g., ‘offer a conceptual analysis of the ‘various meanings’ of authenticity in educational discourse’ (Dishon, 2021); quotation marks ours), we operationalise our approach as follows: first, it is based on the available reviews on the topic over the last two decades (11 reviews). Second, within these reviews, we identify a set of 22 aspects of authenticity (discussed in detail in the main body of the contribution) and provide evidence that this set provides satisfactory coverage of the educational use of the term in the following way: when displaying the total number of aspects discussed in reviews of the topic over the position of the reviews in chronological order (see Fig. 2), this curve shows a strong increase in the first four of five papers, and a kind of saturation from paper eight on. In other words, the knowledge about different conceptualisations collected in the reviews first shows an appreciable growth, then a kind of saturation as the field is increasingly explored—this is what reviews are supposed to do. Taken together, our discussion of ‘authenticity’ in science education is based on the coverage provided by the available reviews in the field and on the finding that this coverage attains a plateau for at least the last five papers (covering roughly one-and-a-half decade). It is in this sense that the set of conceptualisations we analyse provides ‘sufficient coverage’; that is, it covers most of the current conceptualisations found in literature.

Additionally, we include papers about individual aspects of ‘authenticity’ (i.e., not reviews), which serve as examples and illustrations, and for which no specific selection method was applied (except their suitability for the intended purpose).

3 Description of the Model

3.1 Structure of the Model

The model includes two dimensions (see Fig. 3) often mentioned in literature (Bennett et al., 2002; Lee & Butler, 2003; Shaffer & Resnick, 1999; Splitter, 2009; Watkins et al., 2012):

1. Real-world authenticity
2. Disciplinary authenticity

It is completed by a third dimension (Hutchison, 2008; Krapp & Prenzel, 2011; Nicaise et al., 2000; Shaffer & Resnick, 1999):

3. Personal authenticity

The overall structure of the model is as follows: in the lower horizontal plane of the model, representing various aspects of real-world and disciplinary authenticity (see Fig. 3), the centre marks the point of ‘no authenticity’. The further we move radially outward from the centre, the higher the value of the corresponding aspect of authenticity. However, as we will discuss in detail in Section 3.4 on ‘personal authenticity’, an adequate conceptualisation of ‘authenticity´ requires the perception of learners as an additional independent dimension, depicted in Fig. 3 as a vertically shifted plane.

We will now discuss the various dimensions of the model in detail. First, we address the dimensions *real-world authenticity* and *disciplinary authenticity* (Sections 3.2, 3.3, and 3.4). They represent authenticity from the ‘external’ perspective in the sense of

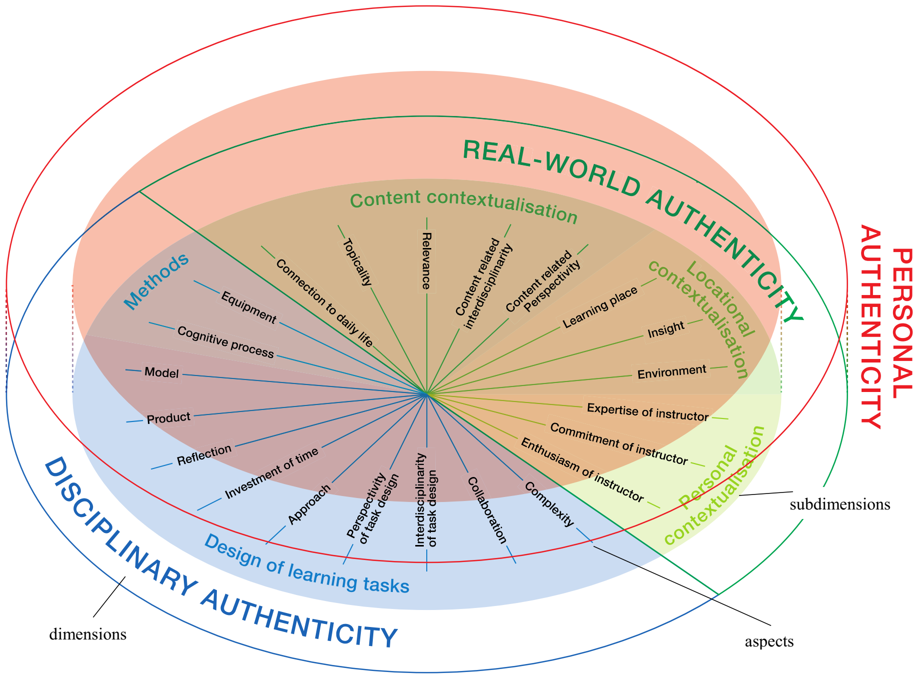


Fig. 3 Real-world authenticity, disciplinary authenticity and personal authenticity

Dishon (2021), which is the perspective of, for example, the instructor or science education researcher, but not that of the student. We then consider the dimension of *personal authenticity* as the 'internal' perspective of each learner in the sense of Dishon (2021), referring to the learners' experience of authenticity, which will be discussed in Section 3.4. A synthesis model will be introduced in Section 3.5.

Additionally, Shaffer and Resnick (1999) consider *authentic assessment* to be a further dimension; we will discuss it in Section 3.6.

3.2 Real-World Authenticity

Newmann and Wehlage (1993) point out the importance of connectedness to the real world, the 'value and meaning beyond the instructional context' (Newmann & Wehlage, 1993, p. 3). There is strong evidence that real-world authenticity helps students achieve more positive attitudes towards science and science learning (Bennett et al., 2007). Krapp and Prenzel (2011) showed that students' interest in physics was increased or at least remained stable if a direct connection to practical life situations was given, whereas without this connection, the majority lost their interest. Gilbert et al. (2011) emphasised that the relatedness to personal or social aspects of students' lives elicits their motivation to learn science.

We want to state clearly that judging what is 'real-world' depends on the subjective view of the instructor or science education researcher (Herrington et al., 2003) or, in other words, the person who is creating, evaluating or investigating the learning opportunity. This subjective view is influenced by the person's experience, culture, demographic traits, education, emotions and so on.

From the instructor's or researcher's perspective, an activity might be believed to be strongly related to the 'real world', but the perception of the learners and even of each learner individually might be quite different (Bennett et al., 2002; Shaffer & Resnick, 1999; Splitter, 2009; Watkins et al., 2012; Weiss & Müller, 2015).

For instance, genetic engineering has a close connection to the real world for a biologist or a person working at a company that trades with genetically altered plants, whereas for a primary school student, this content is hardly related to their own 'real world'. So, links to the 'real world' may look very different to each person.

In the following we want to look deeper into the meaning of real-world authenticity and discuss its conceptualisations. Real-world authenticity often refers to context-based approaches. We suggest using the term *real-world authenticity* as a dimension for this model and the term *contextualisation* to show its different subdimensions. We will further specify each subdimension by describing their *aspects.*

As shown below, an analysis of various uses of *real-world authenticity* in the literature reveals a subdivision into three subdimensions, that is, three kinds of contextualisation. The first applies to the content and to what extent it is contextualised in the real world. The second is the location, where the learning takes place (e.g., a nature field trip or a real research laboratory; Schriebl et al., 2021). The third consists of the person(s) acting as instructor(s) (e.g., a real scientist).

1. Content contextualisation
2. Locational contextualisation
3. Personal contextualisation

These three kinds of contextualisation will be discussed in the following sections.

3.2.1 Content Contextualisation

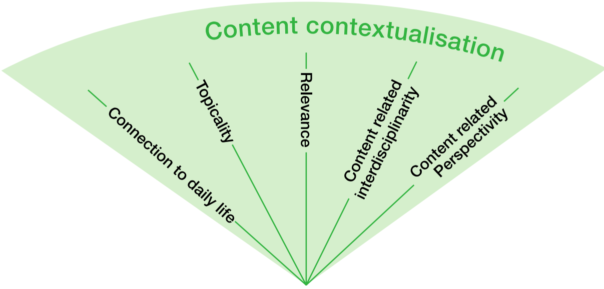
The extent to which content is context-related depends on several aspects. Content might have a close connection to everyday life (see below). But to whose everyday life? That of an adult? Of a child? Of a student? Of a researcher?

Content may not have an immediate *connection to the daily life* of a student but can still be closely related to the daily life of future generations. Such content might not affect the student directly, but society in general (Kuhn, 2009; Newmann et al., 1996; Snape & Fox-Turnbull, 2013; Taasoobshirazi & Carr, 2008; Weiss & Müller, 2015).

The degree of connectedness to daily life might vary depending on, for instance, the age of the learner. While the example of genetic engineering (see 3.1) is not closely related to a typical primary student's daily life, it might be so for an upper secondary student able to vote and willing to participate in democratic decisions, such as those concerning genetically modified organisms. (Fig. 4).

Content with a good chance of fostering interest in science, especially for girls, is provided by biomedical contexts (Hoffmann, 2002). Health, nutrition and the functioning of our senses are examples that feature prominently in everyone's everyday lives and those of one's relatives. Figure 5 offers an instructive finding in that respect: when asking about interest in the same physics topic framed in different contexts, it turns out that girls' interest for a biomedical context (e.g. the heart as a blood pump) is much larger than for a technical context (e.g. a pump for extracting oil from the Earth). For boys, interest for both

Fig. 4 Content contextualisation



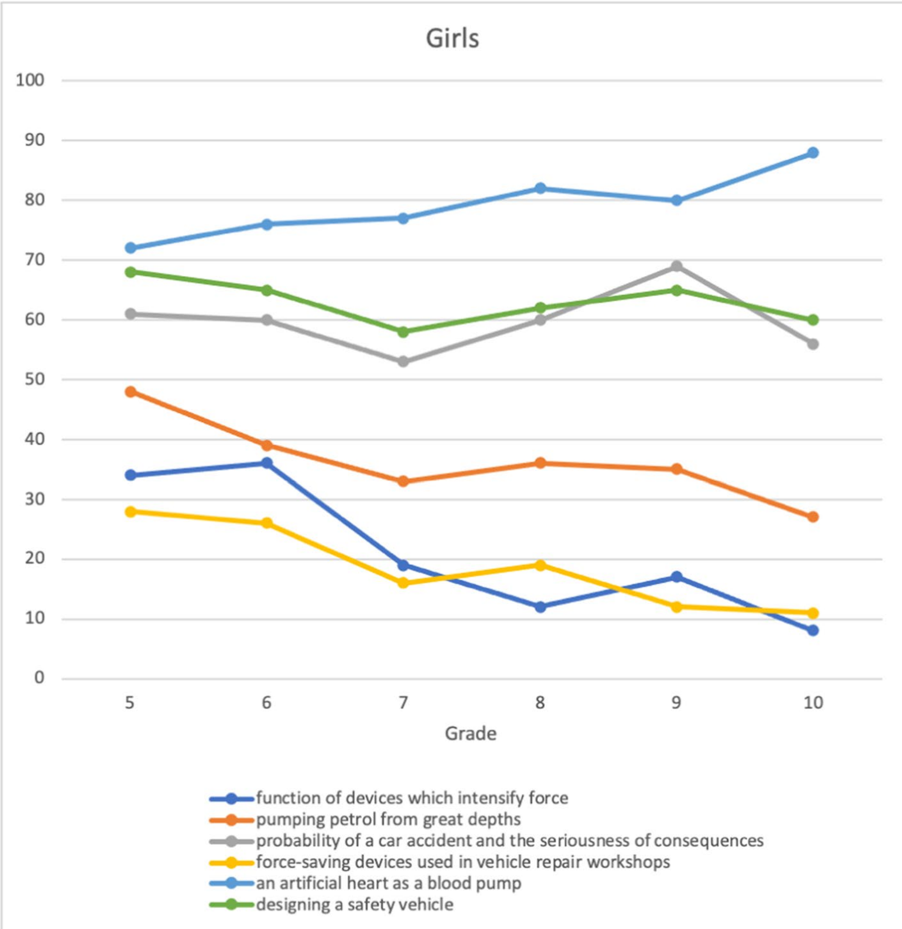


Fig. 5 Percentage of girls with 'great' and 'very great' interest in selected contexts for the topic of mechanics (motion, force, pressure; Hoffmann, 2002)

contexts is similar and rather high (70% in terms of percent of maximum possible score (POMP); Cohen et al., 1999). An example of successful implementation of medical contexts into physics teaching is provided in the work of Colicchia (2002) and Waltner et al.

(2010). Effect sizes for interest development before and after the sequence are + 0.45 with biomedical context and – 0.52 without.

Topicality is a second indicator for the contextualisation of content. Climate change, renewable energy and biodiversity loss—to mention but three examples—are of high topicality for today's society, and some contents seem to have timeless topicality—such as waste problems or deforestation. The third indicator, *relevance,* must be made more specific by the question 'relevant for whom?' Content can be of relevance for humanity, for society, for the economy or for science itself, pushing research further. We distinguish it clearly from 'personal relevance'—meaning the personal rating of the relevance of a topic for oneself—which in this model is an aspect of *personal authenticity*. So, the aspect *relevance* refers to the human, societal, environmental or economical relevance of content.

Many of humanity's current problems can only be solved by collaboration between different disciplines. There are new fields of study such as 'interdisciplinary science', 'life science' and 'environmental science' at universities and vocational schools, with their study plans requiring interdisciplinary components (Bundesrat, 2009) and curriculums worldwide foster interdisciplinarity in science (or rather, science, technology, engineering and mathematics (STEM)) education (Millar, 2020; Ortiz-Revilla et al., 2020; Wang & Song, 2021). As soon as content is put into a modern context, the questions or problems in focus are often *interdisciplinary*.

To truly understand and investigate content in a given context, various *perspectives* have to be considered. For instance, climate change content implies several perspectives, such as its impact on society, on biodiversity and on the economy.

3.2.2 Locational Contextualisation

A wide range of out-of-school *learning places* offer learning experiences, but these experiences are not per se authentic just because they are outside the classroom. For example, a science centre can offer special hands-on activities that are motivating for learners. But an innovative teacher might use the same hands-on activities in the classroom. In this case, the authenticity of the science centre is comparable to or only slightly higher than the authenticity of the classroom. Besides science centres, there are genuine research institutes or universities that offer programmes for schools. On the one hand, such a place can offer a highly authentic environment, especially if *insights* into scientists' work are provided. On the other hand, the authenticity of the same research institute or university is considerably less if these *insights* are lacking, for example, if the programme takes place in a separate room like a classroom, away from the places where scientists work. School labs at universities and research institutes therefore range from medium- to highly authentic *locational contextualisation*, depending on the *insights* offered (Braund & Reiss, 2006).

The aspect *environment* refers to the surroundings where the actual learning place is located. For the investigation of the ecosystem of a pond, the instructor or teacher can set up an aquarium with some animals from a pond inside the classroom, go outside to the school pond or visit a natural pond in a nearby forest. The learning place (the pond) is the same in examples two and three. However, the environment varies. The school pond is, to a certain degree, deprived of its authentic environment. At the

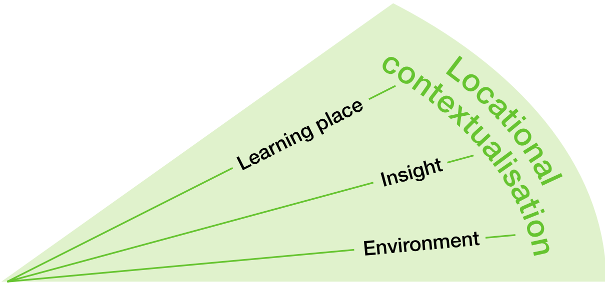


Fig. 6 Locational contextualisation

natural pond in the forest, the students get the opportunity to investigate an ecosystem embedded in an authentic environment (Billett, 1994).

In the example given before, the aquarium as a learning place differs from the pond. The same applies to other out-of-school learning places. The main purpose of a research institute such as CERN in Geneva is to carry out real, authentic scientific research—public relations are important, but not the main focus. The main purpose of a museum or science centre is to bring the visitors closer to science. In cases where scientific research is done at a science centre, it is not the main focus. A classroom has no *locational contextualisation* per se, since it is used for any content or subject and offers students a place to learn all kinds of things. There is no immediate connection to a specific context (Fig. 6).

3.2.3 Personal contextualisation

We now turn to a third subdimension of real-world authenticity, focusing on the person acting as the instructor.

De Bruyckere and Kirschner (2016) found four criteria according to which secondary students determined teachers' authenticity: *expertise, passion, unicity* and *distance*.

The person taking the role of the instructor can be the teacher, a museum educator, a scientist, and so on.

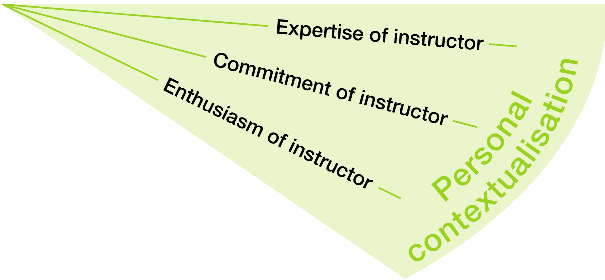
The aspect *expertise* refers to the background of the person instructing or guiding the students or visitors. An instructor who works in science research most of the time and therefore has deep insight into the topic, the methods used and procedures followed, can provide a higher level of authenticity than a teacher who has to acquire their knowledge from books and media and spends, or has spent, less or no time conducting scientific research.

This person's outer appearance and whether this is considered authentic by the students or visitors are not part of this subdimension but will be discussed in the dimension of *personal authenticity*.

The aspect *commitment* allows us to differentiate between various scientists, teachers or museum educators acting as instructors. A scientist is probably very committed to their research, because they chose their specific research topic. Teachers and even museum educators have a wider range of topics they have to teach and so may not be committed to one single topic in the same way. They have their personal interests and also time constraints on which they base their commitment to the topic.

An instructor who teaches and motivates the students with *enthusiasm*—De Bruyckere and Kirschner (2016) call it *passion and enthusiasm*—is convincing and inspiring to learners and visitors. *Unicity* can be understood as a result of enthusiasm, which leads to 'unique' lessons.

Fig. 7 Personal contextualisation



The aspect *distance* (De Bruyckere & Kirschner, 2016) focuses on the relationship between teacher and student which should be neither too close nor too far. It was purposefully omitted from our model, as the main focus here is on the person's authenticity in the context of real-world authenticity. Nevertheless, this criterion plays an important role in the interaction between learners and instructors, albeit on a more general pedagogical level, which goes beyond the intended scope of model we want to develop. The other three aspects relate to the instructor's real-world authenticity and are therefore included in the model (Fig. 7).

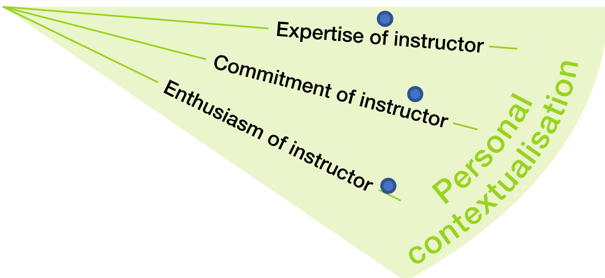
It is important to emphasise that *personal contextualisation* considers only the instructor's or researcher's perspective, not the student's or visitor's. In the attempt to create a learning environment that is intended to be as authentic as possible, person A, who has some expertise, is very committed to the topic and enthusiastic about sharing the insights, provides a higher level of authenticity than person B with less expertise, especially if this person is not very committed or enthusiastic (Figs. 8 and 9).

3.3 Disciplinary Authenticity

Watkins et al. (2012) define disciplinary authentic activities as 'those that use tools – such as concepts, equations or physical tools – in ways and for purposes that reflect how the disciplines build, organise and access knowledge about the world'. In that respect, they emphasise that disciplinary authenticity is not a tool that is specific to a given discipline as such, but rather a question of 'how the tool is used and for what purpose'.

Anker-Hansen and Andrée (2019, p. 61) found in their review that the use of the term 'authentic as comparable with the practices of professional scientists' (in their terms 'cultural' authenticity, as being related to the culture of doing science) was the one most

Fig. 8 Person A, high level of authenticity in the subdimension 'personal contextualisation'



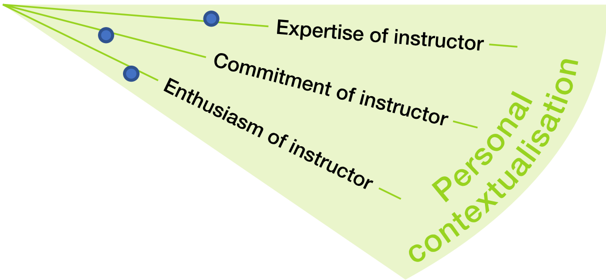


Fig. 9 Person B, low level of authenticity in the subdimension 'personal contextualisation'

common in the science education literature; they state that this 'might not become very personally authentic', a point to which we return in Section 3.4.

van Eijck and Roth (2009, p. 633) describe authentic experiences as ones in which students participate 'in any form of activity where science is also brought to bear on decision-making, as long as this activity is real rather than artificial'. They also emphasise that students need 'the opportunity to participate through actions' rather than only observe.

We suggest dividing the dimension of *disciplinary authenticity* into two subdimensions, namely, *design of learning tasks* and *methods*.

3.3.1 Design of Learning Tasks

In the dimension of *real-world authenticity*, authentic content may have been chosen, but this alone does not make the learning authentic. In this broad and multidimensional understanding of authenticity in science education, the way a learning activity is designed is crucial (Fig. 10).

Herrington et al. (2003) based their research on a broad literature review and suggest 10 characteristics of authentic learning activities. Not only should content be closely related to the 'real world', but also the design of the learning task. The learning activity should 'match as nearly as possible the real world tasks of professionals in practice' (Herrington et al., 2003). This is certainly a characteristic that can profoundly add to the authenticity of

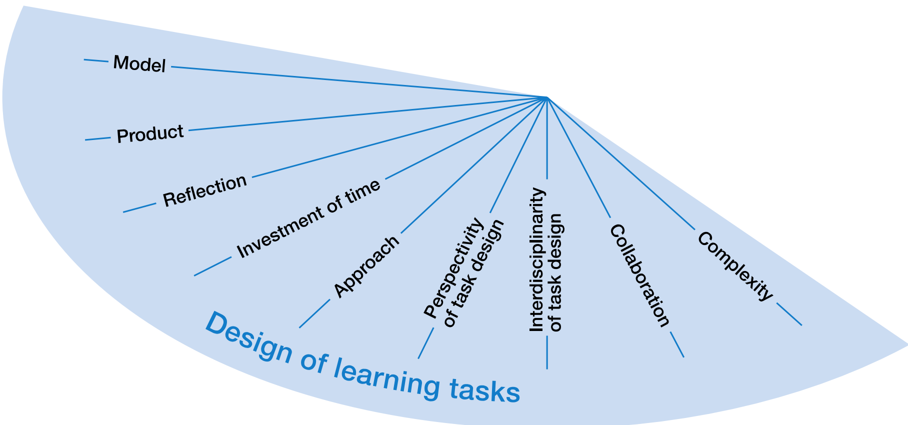


Fig. 10 Design of learning tasks

a learning activity. At the same time, it is hard to achieve at school. Only rarely can 'real research' be accomplished at school. A big part of the curriculum compromises the comprehension of achievements and current research in science. Nevertheless, the latter should be pursued and realised as much as feasible.

If we look more into the characteristics of the tasks which professionals face, the implementation of some of these criteria in science education becomes more realisable.

One of these criteria is the *complexity* of a task (Chinn & Malhotra, 2002; Herrington et al., 2003; Honebein et al., 1993; Lee & Butler, 2003; Nicaise et al., 2000). Some tasks offered at school only provide the information needed to solve a given task. These kinds of tasks have their place and are designed to practice certain skills, but they are far from the complexity of a task faced by professionals. To give students a rather complex task can be one way to increase the authenticity of the learning task.

To solve these complex tasks, professionals *collaborate*. The criterion of *collaboration* should be implemented in an authentic task as well (Herrington & Herrington, 2006; Marx et al., 1997). Meta-analytic results provide strong support that collaborative learning has strong positive effects for many domains of learning (collaborative vs. individual learning, achievement, $d \approx 0.6$, (Hattie, 2008); quality of reasoning, $d = 0.97$, Johnson & Johnson, 2009). For science learning in particular, results for achievement were found to be even more positive ($d = 0.95$, Schroeder et al., 2007).

For many current problems, a collaboration between different disciplines is crucial to find solutions. Even in the case of a purely disciplinary problem, scientists collaborate and seldom work on their own. The aspects of *perspectivity* and *interdisciplinarity* are mentioned in the aspect of content contextualisation, but they should also be considered in the design of a task. Students should be encouraged to take a variety of perspectives into account (Honebein et al., 1993; Toth et al., 2002). An authentic task challenges students to use knowledge and strategies from different domains (Bennett et al., 2002; Buxton, 2006; Herrington et al., 2003). For example, they can be encouraged to look at environmental issues from a societal, environmental, economical (etc.) perspectives or to take on different roles in a discussion. An example for such an integrative contextualisation is the 'science, technology and society' (STS) approach, a line of thought emphasising connections between the natural sciences and technology with society on the one hand and with culture on the other hand (Aikenhead, 1994a, 1994b; Bybee, 1991; Fensham, 1985; Solomon & Aikenhead, 1994). In the 'Iowa project', a well-investigated and internationally recognised best-practice example for STS, very large effect sizes were found ($d = 1.52$, Yager & Weld, 1999). Another STS project in chemistry found medium effects ($d = 0.63$; Winthur & Volk, 1994).

A further design aspect is the openness of the *approach,* which allows for several paths and solutions (Bennett et al., 2002; Braund & Reiss, 2006; Herrington & Oliver, 2000; Herrington et al., 2003; Snape & Fox-Turnbull, 2013). A task featuring an open approach is problem-oriented, is open-ended and requires learners to apply a variety of strategies and to investigate various possible solutions. As Kruse et al. (2021) showed in the qualitative part of their study, the openness of the task is also mentioned by sixth-grade pupils as an indicator of whether they are doing 'real science'.

Authentic tasks are not completed within minutes or hours but need significant *investment of time* (Herrington et al., 2003). Not only does an authentic task require more time to solve, but it should also be focused on and addressed over a longer period of time (Snape & Fox-Turnbull, 2013).

Professionals have to *reflect* on their work and progress. The extent to which learners have to make choices and reflect on their learning and progress adds to the authenticity of a learning activity (Herrington & Herrington, 2006).

The *product* (or outcome) of the task should have a value of its own instead of just being an exercise or preparation for something else (Herrington et al., 2003). In a recent study involving secondary level-one learners, Güdel et al. (2019) showed the added value of 'product orientation' on learners' interest, for example, by complementing science teaching with the technical design of real, useable products and with a focus on everyday situations and authentic problems from the professional world. Moreover, while the well-known 'gender gap' for technology interest in general was confirmed (boys being more interested than girls, $d \geq 0.7$), no gender differences were revealed regarding interest for 'planning and designing' nor 'designing an eco-friendly product'.

Finally, a task can either be designed as a *model of simulation* or a *model of participation*. In the first, a *simulation* of the professional's tasks and work is created for the students, whereas in the model of *participation* the students contribute to a real scientific task (Barab et al., 2000; Radinsky et al., 2001). In a school context, participation could be achieved through programmes such as GLOBE (Global Learning and Observations to Benefit the Environment), providing students 'with the opportunity to participate in data collection and the scientific process' (U.S. Government, 1995). Most often however, learning activities can only provide simulation, as real participation is hard to achieve. Both models provide authenticity, with the model of participation having a higher degree than the model of simulation (greater and smaller distance to the centre, respectively).

3.3.2 Methods

The *methods* define the second subdimension of *disciplinary authenticity* (Fig. 11). A first aspect of this subdimension refers to the *equipment* used. Usually at school, laboratory equipment made specifically for this purpose is used. The use of authentic equipment as used by scientists can increase the authenticity. For example, an instructor can use a gas chromatograph to determine the gases in a reaction. Nevertheless, we must take into account that this equipment is often too expensive or complicated to be used in schools. In connection with the learning place (see aspect 'locational contextualisation' above), research institutes, especially, have an opportunity to implement authentic equipment to increase authenticity.

Over the past 10 years, the Institute for Science Teacher Education in St. Gallen, Switzerland, has developed an approach to science and technology based on analysis modules around high-tech instruments used in everyday research and development. The aim of providing authentic instruments is to give students a privileged and contextualised access to novelty, to reduce their fear of technology and to improve their understanding of the digitalisation of analytical methods and scientific data. By offering authentic access to scientific practice, the mobiLLab and Berzelius projects aim to strengthen a contextualised approach to science and technology education (www.mobillab.ch and www.berzelius.ch).

The *cognitive process* (Chinn & Malhotra, 2002; Schumacher & Reiners, 2013; Shimoda et al., 2002) can be closely related to authentic scientific inquiry, in which control-of-variables strategies and the research cycle are essential tools, in contrast to 'typical classroom inquiry'.

Scientific inquiry includes generating a research question, planning measurements, making observations, interpreting the results, to name but a few steps. Chinn and Malhotra (2002) analysed cognitive processes in science and summarised them in a table, contrasting authentic and simple inquiry tasks.

Kruse and colleagues (2021) used the concept of guided inquiry to enhance students' concepts on the nature of science. Pupils act like scientists or imitate them. They found the combination of both scientific inquiry and rich 'context is likely to lead to the most robust NOS (nature of science) learning' (Kruse et al., 2021, p.1224).

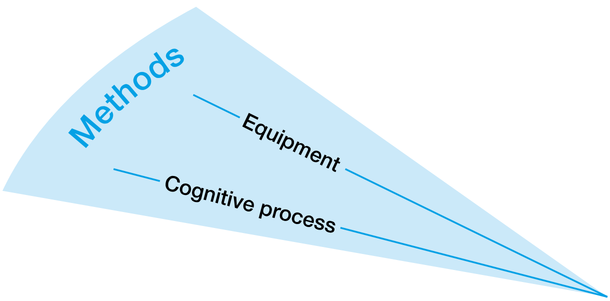
3.4 Personal Authenticity

A characterisation according to the dimensions of *real-world authenticity* and *disciplinary authenticity* with their differentiation into subdimensions and aspects exclusively focuses on authenticity from the perspective of the instructor, researcher, or developer: is this learning material connected to real life, does the out-of-school learning place provide 'locational authenticity', and so on? In general, the two dimensions of *real-world* and *disciplinary authenticity* characterise the degree to which learning activities, materials and environments are provided with one or several aspects of authenticity from the instructor's or researcher's point of view. That is to say, it is a degree of their *intended* authenticity. Petraglia (1998) called this 'preauthenticitation', defined as 'educational practice whereby 'authentic' learning technologies, environments, or pedagogies are devised prior to, and independent of, a learner and a specific learning context'. He states that preauthenticitation implies an 'act of faith that what seems real (and thus, authentic) to me, seems real (and thus, authentic) to my students' and provides a detailed critique for reasons of both epistemology and practice of constructivist education. Similarly, Barab et al. (2000) stated that authenticity cannot 'be prescribed to a learner by the instructor'.

Gulikers et al. (2005) emphasise the importance of students' actual perception, as it cannot be assumed that a learning environment that is designed to be authentic is also perceived as such by leaners, and they conclude that 'authenticity is in the eye of the beholder' (Gulikers et al., 2008). What is said here about the importance to take into account differences between students' and educators' perceptions of authenticity fits well into work about such differences regarding education in general (Könings et al., 2014).

Weiss and Müller (2015) show that for the PISA (Programme for International Student Assessment) science items, supposed to ensure 'relevance to students' interests and lives' (OECD, 2007, p.36), there is a large gap between how teachers and pupils perceive the authenticity and connection to reality (teachers vs. pupils: Cohen $d = 1.34$).

Fig. 11 Methods



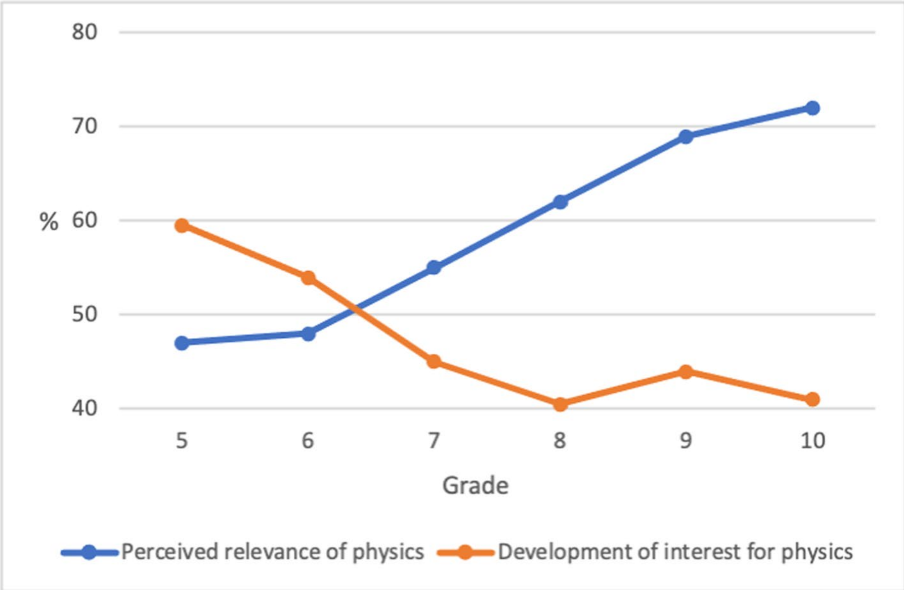


Fig. 12 Development of interest for and of perceived relevance of physics across adolescence (Muckenfuß, 1996) (y-axis: percentage of maximum possible (POMP, Cohen et al., 1999) for the scale of interest)

Moreover, note that even the perceived (societal) relevance (high degree of content contextualisation, Section 3.2.1) of a given context does not automatically imply high interest, as it is often assumed: Fig. 12 displays a striking 'scissor' shape, with a strong discrepancy between the perceived relevance of physics, which increases over the years, and interest, which shows a marked decrease.

Dishon (2021) calls the dimensions of authenticity described in Sections 3.2 and 3.3 'external and supposedly objective', whereas *personal authenticity* is 'internal' (Dishon, 2021, p.158). The actual experience of authenticity, the 'feeling of authenticity' (Betz et al., 2016) occurs within each learner's perception, on which the instructor has limited influence.

As Kruse et al. (2021) were able to show, 6th-grade students rated (from their 'internal' perspective) the authenticity of a highly contextualised activity (in our model, with high scores in the two-dimensional part, that is to say, the 'external' perspective) lower than a decontextualised activity (large effect size,[2] d=—1.07).

Therefore, we introduce a third dimension of the model, the student's perception of authenticity, which we call *personal authenticity*[3] (Anker-Hansen & Andrée, 2019; Shaffer & Resnick, 1999). *Personal authenticity* is a principal dimension and is visualised by the height (z) above the plane formed by real-world authenticity and disciplinary authenticity

[2] On the basis of the equations given in Fritz et al. (2012), the effect size is calculated as $r = z/N^{1/2}$ and transformed to d; this yields $r = 0.47$ and $d = -1.07$, i.e. a large effect size (contrary to what Kruse et al. (2021) say); the minus sign accounts for the direction of the effect.

[3] Note that *personal authenticity*, i.e. authenticity *for* a given person (a learner), is to be distinguished from *personal contextualisation*, i.e. an authentic context provided *by* a given person (a teacher or instructor).

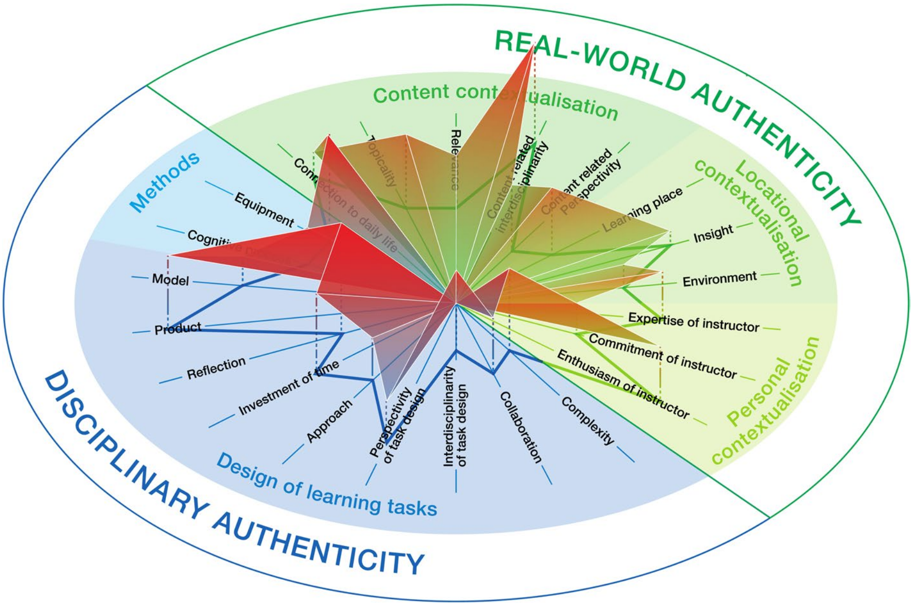
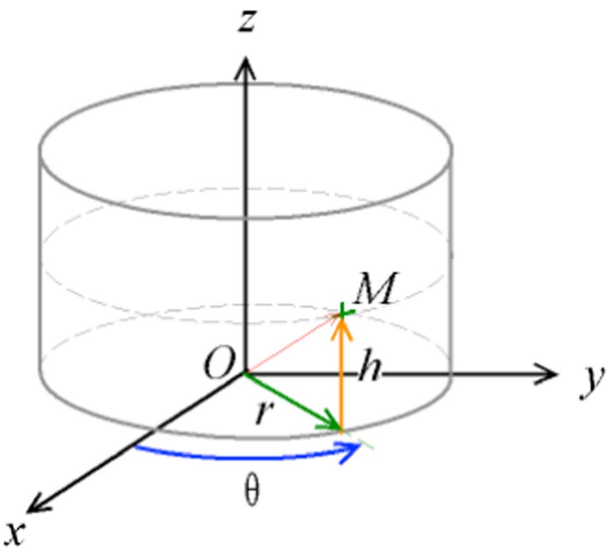


Fig. 13 The complete model including an illustrative example of expressed personal authenticity for one student

Fig. 14 Cylinder coordinates; Source: https://commons.m.wikimedia.org/wiki/File:Coordonnees_cylindriques.svg (public domain)



(see Fig. 3). Note that, by the model's construction, personal (internal) authenticity (height, z-axis) must be considered for each subdimension and each aspect of external authenticity (the horizontal axes). While we refer to the 'dimension' of personal authenticity in the singular, it takes as many aspects—plural—as external authenticity. Figure 13 shows an example of the complete model for a given learner. The shape of the 'crown' would look different for each student. We will now turn to a synthesis model integrating these three dimensions of authenticity.

3.5 A Synthesis Model for Authenticity

The basic structure of the model is that of a cylindrical coordinate system (Weisstein, 2002). This is a coordinate system (see Fig. 14) that starts with polar coordinates (radius, direction) in a plane (the 'base' of the cylinder) and extends them along a third coordinate that measures the height of a point with respect to the plane, very much in the same way that a Cartesian coordinate system is extended from two to three dimensions.[4] The characteristics of the multidimensional concept of 'authenticity' are identified with this geometrical model as follows.

The base is a circle with the origin (O) in the centre, representing a 'zero' point with respect to authenticity. Various directions (coordinate θ) represent various aspects of authenticity (e.g., connection to everyday life). The distance from the origin (coordinate r) along each radial line then represents the degree of authenticity of a given element of learning material or learning opportunity (Labudde et al., 2005). So, the further we move radially outwards from the centre in a given direction, the stronger the 'external' authenticity of the respective aspect.

The base circle is split into two sectors (visualising two 'dimensions' of the concept authenticity), one for *real-world authenticity* and one for *disciplinary authenticity* (see Fig. 3). These two sectors (the dimensions) are then subdivided into smaller sectors (the subdimensions). In each subsector or subdimension, there are radial lines that represent the 'aspects' of the respective subdimension, the most fine-graded differentiation of the multidimensional concept of authenticity.

The above coordinates (r: degree, θ: aspect) relate to *intended* authenticity, as related to some learning material or opportunity, and as conceived by some instructor or developer, the 'external' perspective (Dishon, 2021). However, as discussed in detail in the section on *personal authenticity* (3.4), authenticity as *perceived* by a learner must be taken into account as an essential educational factor. So, the model needs the third dimension of the cylinder coordinate system, height, for every single aspect, which is different from learner to learner and represents perceived authenticity, the 'internal' perspective (Dishon, 2021). So, moving outwards along the different axes is not enough: the height is a crucial element to truly analyse and achieve authenticity as a productive factor in science education.

In terms of measurement levels (Perron & Gillespie, 2015), the 'aspect' (θ) coordinate is a nominal variable, and the (intended) 'degree' (r) coordinate is an ordinal or interval variable, depending on the type of instrument used. Together, the aspect and intended degree coordinates (θ, r) form a 'radar' (also 'spider' or 'star') plot (Chambers, 2018). Note that in

[4] Note that *dimension* is used here with two meanings, one conceptual and the other geometrical: on the one hand, as a dimension of the concept of authenticity (see *real-world authenticity*), in line with the use of 'dimension' in the literature on authenticity; on the other hand, as a dimension of a cylinder coordinate system, in the sense of 'dimension' in geometry. If the meaning is not clear from the context, we will denote the latter by dimension_g (like 'geometrical') to distinguish it from the former.

a radar plot, only the θ, *r* coordinates can be interpreted, while a transformation to the x, y coordinates of the plane is not possible due to the different measurement levels of θ and *r*.

Taking these all together, we arrive at a three-dimensional model of authenticity: every aspect of intended authenticity corresponds to perceived *personal authenticity*, represented by the height (h) in Fig. 13—each student's perception of each aspect of authenticity. This results in the shape of an irregular crown: the higher the spike of the crown, the higher the *perceived* authenticity in that particular aspect. The larger the radius of the crown, the higher the *intended* authenticity. Figure 13 shows a model as an illustrative example for one student: The spikes show that the perceived authenticity of the learning place (locational authenticity) is quite high, whereas the perceived authenticity for the aspect *connection to daily life* in the subdimension *content contextualisation* is rather low. However, the intended authenticity by the instructor of the same aspect, *connection to daily life,* is very high in this example. In this way, every aspect of the dimensions presented on the basis of the cylinder may be perceived differently by each learner, and differently from the intended authenticity. For example, in the subdimension *personal contextualisation*, we would expect that if we give learners the opportunity to learn from a 'real scientist' who is very committed to their work, this will provide a higher level of authenticity. The intended *personal contextualisation* of authenticity in this example is very high (large value of *r*). In the student's perspective, however, this might not be the case. Each student has a certain expectation of how a scientist looks and behaves. Schumacher and Reiners (2013) found that even certain pre-service science teachers had naïve images of a chemist 'as a (spectacled) man who works alone in his laboratory' (Schumacher & Reiners, 2013, p.2181). So, even a scientist being very committed to their work simply does not match the picture of each student's expectation. As a consequence, the *perceived* authenticity within a learner will be low, no matter how high the intended authenticity, whereas for another learner it might be high and, therefore, more closely matching with the intention.

In this way, the model would show a different, individual crown shape for each learner.

3.6 Authentic Assessment

In this model, we do not see *authentic assessment* as a separate dimension, but rather as a complementary approach within the same framework. In this article, we refer to learning opportunities or learning environments that are developed according to the three dimensions and multiple subdimensions and aspects of the model. In *authentic assessment,* the same subdimensions and aspects must be considered as in the case of developing a learning environment. The goal is either a learning environment or an assessment, but in both approaches the same model can be used for this purpose.

4 Discussion: a Tool for Practitioners[5] and Researchers

4.1 General Discussion

A learning environment, learning activity or task is only effectively authentic for a given aspect of authenticity, if it is perceived as such from the learner's perspective. Even if we

[5] By 'practitioners' we mean science educators responsible for, e.g. the development of teaching materials or design of offers at science labs and museums.

consider a large number of aspects of authenticity or a high degree of intended authenticity in creating a task or environment, it is only when students can see this authenticity themselves that the intended beneficial effects of authenticity can be achieved. For instance, Lewalter and Geyer (2009) found that the ‘perceived topical relevance’ is by far the strongest predictor of interest ($r^2 = 0.45$ and 0.50 for of ‘catch’ (initial) and ‘hold’ (medium-term) aspects of interest). We therefore agree with other authors (Gulikers et al., 2008; see also 3.4) and state, by analogy to a famous saying, ‘Authenticity is in the eye of the beholder’.

So, does personal authenticity not undermine the other two key dimensions of the model (the horizontal axes in Fig. 13)? This is a very important point to be clarified. The reasoning here is as follows: no, the other two dimensions are still indispensable. Indeed, they guide researchers and practitioners on the basis of available research on different conceptualisations of authenticity. But it is important to recognise that there is the additional dimension of learners’ perception to be taken into account, which tells us whether the educational intentions indeed had the intended effects. So, the third dimension extends the importance of the other two, but does not undermine them. In a wider perspective, the difference between the ‘hypotheses’ (teachers’ intentions) and the ‘results’ (learners’ perceptions) and the conclusions drawn from them relate the present model to the view of teachers as ‘researchers of their own teaching’ (Amabile & Stubbs, 1982; Roth, 1995).

Personal authenticity is not easy to influence and observe. By creating learning activities with high levels in the dimensions *real-world authenticity* and *disciplinary authenticity,* we hope to achieve a high level of resulting *personal authenticity*. To what extent the emergent process happens as intended and the *personal authenticity* is actually achieved can only be evaluated with data obtained from students (such as questionnaires and interviews). Methodologically, this is a ‘manipulation check’, that is to say a control mechanism to see whether experimental variation (‘manipulation’) really has the intended effects (Harris, 2008; VandenBos, 2015). Research on authenticity should always include such a manipulation check, in other words, gather data to observe whether the intended authenticity really leads to perceived authenticity. The results of such data gathering can help to adapt the practitioner’s or researcher’s view of what they perceive as authentic from their point of view.

In this way, the authenticity of a learning task or learning environment can be improved in a circular process. We create learning environments or tasks that, from our point of view, are highly authentic. The students’ perception must be evaluated and, on this basis, we adjust the various aspects of authenticity of the learning environment or learning task given.

Eventually, actual authenticity can only occur in the learner’s perspective when interacting with the environment and learning task (Betz et al., 2016; Petraglia, 1998). The ‘preauthenticitation’ on the dimensions of *real-world authenticity* and *disciplinary authenticity* are nonetheless important aspects to consider when creating a learning task or learning environment. We have to make sure that we create learning tasks and environments that, from our perspective, provide a high level of authenticity from the outset.

Based on the model for authenticity in science education presented here, we suggest a spider plot as a tool for assessing the extent of a learning activity’s authenticity (see Fig. 15). A practitioner or researcher marks their perception of each aspect in the spider plot as shown in this fictitious example.

We want to emphasise that the value on the scale does not mean a rating in the sense of ‘the higher the better’, but it should show the extent of authenticity contained in the activity. Depending on the educational goals, on the topic or on the environment, certain aspects can be higher or lower for good reason.

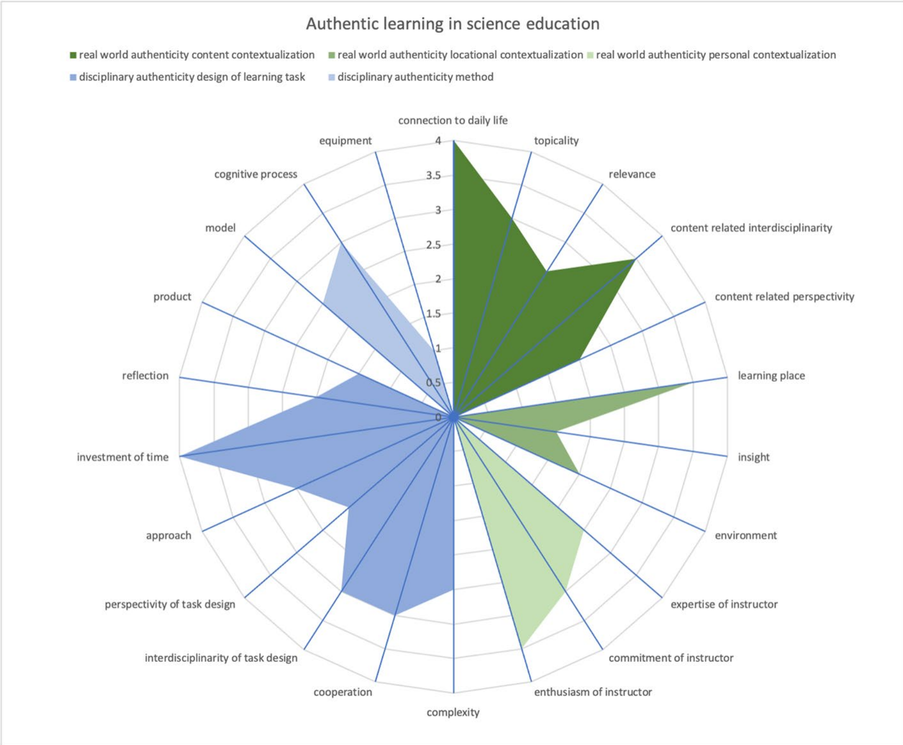


Fig. 15 Spider plot for the dimensions real-world authenticity and disciplinary authenticity

To include the student's perspective and achieve authentic experiences, we need instruments and tools to measure and evaluate the student's personal perception of the various aspects of authenticity. The perception of authenticity is different form learner to learner. However, it is also conceivable to work with average values, for example differentiated by gender. The results from such evaluations should be used for designing, creating and improving authentic learning opportunities, for example, to find contexts and task designs that are perceived as authentic by female as well as male students.

Additionally, an instructor or teacher should try to persuade their students of the authenticity of a certain place or topic up to a certain degree (Petraglia, 1998) and also let them choose relevant topics from their own point of view.

4.2 How Researchers Can Use the Tool

For researchers working with the concept of authenticity, the model and the tool offer an opportunity to design and visualise their studies. Various aspects of authenticity stand for variables, which can be varied or controlled.

It should also serve as a starting point for discussions about authenticity in science education. We encourage the further development of the model and its adaptation to other disciplines. Focus should be placed on the relationship between intended ('external') and experienced ('internal') authenticity. For example, the model can be further developed in an evidence-based way by developing suitable scales to survey the authenticity experienced by students ('internal').

4.3 How Practitioners Can Use the Tool

In the creation and design of a learning environment, the two dimensions *real-world authenticity* and *disciplinary authenticity,* with their subdimensions and aspects, must be taken into account. The same applies to authentic assessment. Carefully considering these various aspects helps the instructor in developing a learning environment that they would call authentic.

An authentic learning opportunity can be created in different subdimensions by considering the possibilities one has at a school, museum, school labs or similar. Some aspects might only have low levels of authenticity, but authenticity can be increased across all of the model's aspects. For example, a practitioner is developing a learning sequence at school who has no option to visit an out-of-school learning place, so the values in the subdimension *locational contextualisation* are rather low. By choosing highly *relevant* content with high *topicality* and *connection to daily life*, the *real-world authenticity* can be increased. Furthermore, the construction of the task itself can be varied according to the various aspects. Encouraging students to *collaborate* on the task, starting from an open question with several *approaches* and keeping the question ill-defined and *complex* offers further possibilities to increase the *disciplinary authenticity*. The authenticity will vary in the various dimensions: for some learning opportunities, the subdimension *locational contextualisation* can be high but the authenticity of the *design of the learning task* rather low, for other learning opportunities the picture will look different. It is not the aim of this model to state that science education is only authentic when all aspects in the model show a high value.

The aspects show a range of possibilities to create an authentic learning activity, while bearing in mind that exploiting all the aspects to their full extent might end up in frustration for learners (Herrington et al., 2003). The model can help to increase the authenticity of learning tasks, but in developing such tasks, practitioners must also be sensitive in relating the task to student requirements.

When creating a learning environment, practitioners should consider the student's view as much as possible. For instance, when choosing a topic, by asking students which topic is relevant and meaningful to them. Alternatively, when preparing to visit an out-of-school learning place, they can start by introducing to students the relevance of that place for society or in daily life.

To give a concrete example, taken from a real research and development project by the authors, consider a teaching unit about renewable energy to be implemented at level secondary one, content with a high degree of *topicality* and *relevance* from the teacher's and society's perspective. The practitioner/teacher can decide to keep the level of *locational contextualisation* low by teaching in the class room or increase it by visiting an out-of-school learning place, such as a wind power plant or a research institute where solutions for the storage of energy from renewable sources are explored. At the out-of-school learning place, various levels of *personal contextualisation* are conceivable: either the teacher delivers most of the instruction and then only hands over to an expert from the out-of-school learning place for a guided tour, for example, or more emphasis is given to *personal contextualisation* through exchanges with the expert by having them engage in a detailed discussion with the learners. In deciding how high the level of authenticity in the aspect of *personal contextualisation* should be, the teacher will not only consider the abilities of the students but also the *enthusiasm* and *commitment* of the instructor.

The model can help to guide and structure the reasoning of the teacher as follows: first, it provides an overview, which subdimensions and aspects may be considered in different learning environments, so it helps teachers take into account the relevant authentic aspects (in the given example, *relevance*, *locational and personal contextualisation*). Second, it may also help to choose an adequate level of complexity to avoid overburdening the learners. In our example, a teacher might get too enthusiastic about implementing authentic learning opportunities by combining the visit to the research institute with a learning task design based on an interdisciplinary, complex problem that can only be solved by taking into account various perspectives. The visualisation in the spider reminds the teacher that students might be overstrained, preventing the intended educational effects. This could also have a reciprocal effect on teachers, by leading them to the conclusion that authentic learning tasks are too complex in general. As a result, and out of frustration, the teacher may abandon authentic tasks, while a more adequate conclusion, suggested by the model, would be that too many aspects were implemented at once, and/or a too high a degree of these aspects was sought (e.g. high *interdisciplinarity of task design* and *content-related interdisciplinarity* in combination with very high *connection to daily life*).

In this case, the model also demonstrates that learners can be *gradually* introduced to increasingly authentic learning environments. In this way, teachers are encouraged to venture into authentic settings without the intervention ending in frustration for teachers and learners.

Evaluating the learning environment and the learning task after its implementation provides the instructor with crucial feedback about the perceived authenticity—the *personal authenticity*. On this basis, the authenticity can be adapted and increased. Step by step, we might get closer to authenticity, given that we can never reach all students and that achieved authenticity remains a relative concept that develops in the interaction of learner, instructor, context and environment.

5 Conclusions and Perspectives

Our model visualises the multidimensionality of authenticity and leads to a tool that can be used to increase authenticity in science education. Even though our model looks like a crown, in the end there is no royal road to achieving authenticity in science education, but countless varieties of paths. Depending on the learning goals, authenticity can be increased within certain subdimensions or in particular aspects described in this paper, whereas other aspects are kept low for good reason. To aim for high values in all aspects of authenticity described will most probably lead to cognitive overload. The practitioner or researcher must choose mindfully. A learning environment can provide authenticity in some aspects while other aspects are kept low and the overall experience will be an authentic one nonetheless.

By adapting the subdimensions and aspects to the given disciplines, its tools and specific properties, the model presented here can be used for visualising authenticity not only in science education but in education generally. Existing models such as the one from Betz et al. (2016) or the one from Snape and Fox-Turnbull (2013) do not stand in contradiction to the model presented here, but can be seen as a different approach to our visualisation.

We want the model to be understood in a malleable way: aspects and subdimensions can be added and adapted according to further research and results.

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Author Contribution Daniela Schriebl and Nicolas Robin developed the model presented in the paper. Andreas Müller contributed evidence-based studies, the formalisation by cylinder coordinates and other mathematical aspects, and provided critical feedback. Andreas Müller and Nicolas Robin supervised the research project. Daniela Schriebl wrote the manuscript with support and inputs by Andreas Müller and Nicolas Robin.

Daniela Schriebl, Andreas Müller and Nicolas Robin discussed and contributed to the final manuscript.

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Code Availability Not applicable.

Declarations

Ethics Approval Not applicable (the paper does not contain any studies with human participants or animals).

Consent to Participate Not applicable.

Consent for Publication All co-authors declare their consent for this publication (study participants, not applicable, images from other sources, not applicable).

Conflict of Interest The authors declare that they have no conflict of interest.

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