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Research-Based Report of Practice

Re-Thinking Tasks in Inclusive Science Education – New Approaches to Enable Participation

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Structured Abstract

Background: Tasks constitute a crucial element of learning environments as they prompt students to engage with the learning content. Among others, *doing science*, particularly conducting experiments, includes very specific task formats and activities which focus strongly on writing, reading, mathematical, and fine-motoric skills. In order to enable all students to participate in science education, these task formats need to be re-designed, since they present barriers for many learners or even exclude some completely (Stinken-Rösner & Abels, 2021).

Purpose: The purpose of this paper is to demonstrate different approaches to design 'inclusive' tasks that allow all students to participate in investigating the 'Flaschentuten' phenomenon. Acoustics is an essential part of physics education, which is not only challenging for hearing-impaired students. Due to its complexity and high level of abstraction, acoustics is a barrier-loaden topic for many learners. We show how students can engage with the same context on different levels of abstraction, depending on their individual previous experiences and needs and how various scaffolding offers can support individual and mutual learning.

Sample/Setting: The 'Flaschentuten' context is used in the course of an introductory seminar on inquiry-based learning. Over the last three years, more than 100 pre-service teachers investigated the 'Flaschentuten' phenomenon. None of the participants were enrolled in physics study programs at university level. Some already had experience with the context, but none was able to explain the phenomenon scientifically.

Design and Methods: In order to enable participation for all learners, typical tasks connected to *doing science* were re-designed following the *Framework for Inclusive Science Education* (Brauns & Abels, 2021). We chose the context "Flaschentuten", since learners can engage practically with this phenomenon even with no to little knowledge about the underlying scientific content. Additionally, various scaffolding offers (e.g., material, linguistic, cognitive, and communicational) as well as different types of digital media were implemented. Following the design-based research approach, the learning environment was continuously further developed and tasks re-designed in accordance to our observations (and to allow distance learning during COVID-19).

Results: The observations on how learners engage with the context 'Flaschentuten' and the inclusively designed tasks are based on three years of experiences. The context 'Flaschentuten' proved to foster students' situational interest. Typically occurring research questions relate to the characteristics of the bottle, the filling level, the filling material and to the way the bottle is 'played'. The complexity of the corresponding experimental setup and the acquisition of measurements varied depending on students' previous experiences, knowledge and skills. Also, students made use of the re-designed tasks which allowed for new approaches. In particular, the digital media offers (measurement app and digital documentation in form of audios/pictures/videos) were very popular among learners.

Conclusions: In conclusion, the experiences made with the context 'Flaschentuten' show that re-thinking tasks from the perspective of inclusive science education can result in learning environments that enable participation for all learners. Applying frameworks, such as the *Framework for Inclusive Science Education* (Brauns & Abels, 2021), can help teachers to identify potential barriers of contexts, tasks and materials as well as to provide alternative approaches that are compatible with the requirements of inclusive science education.

Keywords: *Inclusion, Inclusive Science Education, Participation, Task Design, Digital Media.*

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1 Introduction

Tasks constitute a crucial element of learning environments as they prompt students to engage with the learning content and transfer their knowledge and skills to new contexts (Reusser, 2013; Stäudel, 2003; Thonhauser, 2008). In many cases, tasks are set in written form, include text-intensive material, such as textbooks or worksheets, and students are asked to give their solutions in written form as well. This uniform orientation is problematic not only from a didactic point of view, but especially from the perspective of inclusive pedagogy. When focusing strongly on reading and writing skills, not all students are able to participate in these learning opportunities – some of them are excluded completely (Wellington & Osborne, 2009). Therefore, new approaches and task formats that go beyond typical 'paper-pencil-worksheets' need to be developed.

Also, contemporary science education is not limited to *learning scientific content*, but aims at fostering students to *reason about scientific issues*, to *do science*, as well as to *learn about science* (Hodson, 2014; Stinken-Rösner et al., 2020) For this reason, conducting experiments, applying scientific methods, and developing (practical) scientific skills play an important role in today's science classrooms. Many of these activities are cognitively demanding and rely on sensory perceptions as well as on elaborated fine-motoric skills. It is up to the teachers to arrange learning environments and tasks, which foster students' individual learning in a way that enables participation for all students.

2 Theoretical Background

Already in 1948, the *Universal Declaration of Human Rights* (UDHR) declared that "everyone has the right to education" (art. 26). When the *Convention on the Rights of Persons with Disabilities* was enacted about 60 years later, in 2006, inclusive education has come under public discussion (UNESCO, 2005). The UNESCO defined inclusion as "[…] a process of addressing and responding to the diversity of needs of all learners through increasing participation in learning, cultures and communities, and reducing exclusion within and from education" (2005, p. 13). With this definition, the UNESCO does not only refer to the inclusion of special needs students, but addresses all dimensions of students' diversity (e.g., gender, ethnicity, culture, religion, socio-economic background, age etc.) (cf. Ainscow, 2007; Werning, 2014). In order to comply with the requirements of increasing participation, the UNESCO (2005) states that inclusion in education "[…] involves changes and modifications in content, approaches, structures and strategies […]" (p. 13). Following this request, we make an attempt to re-think tasks so that they meet the requirements for inclusive science education. Before doing so, we state what *inclusive science education* is characterized by. Later in the article, we present tasks developed around the context 'Flaschentuten' and discuss how far this context and the developed tasks can meet the requirements of inclusive science education.

2.1 Inclusive Science Education

At this time, there is a broad consensus about the main goal of science education: *scientific literacy* for all learners (Bybee, 1997; National Research Council, 1996; OECD, 2019). To achieve this goal, science education needs to address the concept of *scientific literacy* (OECD, 2019; Roberts & Bybee, 2014) whilst (at the same time) taking into account the needs of all students so that they are able "[…] to participate in individualized and collaborative subject-specific teaching-learning processes […]" (Walkowiak et al., 2018, p. 270). Stinken-Rösner et al. (2020) consider these two demands by combining the perspective of inclusive pedagogy with the perspective of science education. By *inclusive science education* they understand the interplay between these two perspectives. In this view, inclusive science education is characterized by central aspects of both, the inclusive and the scientific perspective. Connecting these central aspects represents the idea of *scientific literacy for all learners* (Fig. 1, green hubs).

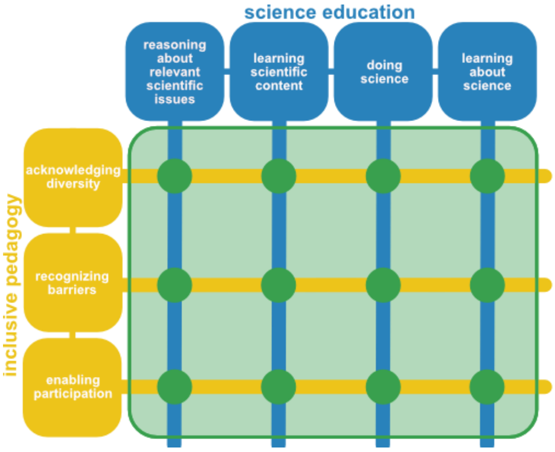


Fig. 1. Inclusive science education as an interplay of inclusive pedagogy and science education, representing the idea of *scientific literacy for all learners* (Stinken-Rösner et al., 2020, p. 37)

In the scheme developed by Stinken-Rösner et al. (2020), the perspective of science education is characterized by four central aspects (blue in Fig. 1):

- *reasoning about scientific issues,*
- *learning scientific content,*
- *doing science,*
- *learning about science*.

These aspects represent the four major learning goals in science education (Hodson, 2014) and incorporate the concept of *scientific literacy* (OECD, 2019; Roberts & Bybee, 2014). The inclusive perspective comprises three central aspects (yellow in Fig. 1):

- *acknowledging diversity,*
- *recognizing barriers,*
- *enabling participation*.

These three aspects can be seen as a triad when moving towards inclusive education (cf. Booth & Ainscow, 2016). In order to provide learning environments that enable learning for all, the diversity of the learning group needs to be acknowledged in a first step. This means to respect all learners with their unique personality and learning conditions, considering their individual potentials as an enrichment for the learning group (Booth & Ainscow, 2016; Mastropieri & Scruggs, 2014; UNESCO, 2005).

To ensure that learning opportunities are designed in a way that does not exclude any students, it is crucial to recognize potential barriers and obstacles that may arise from the interplay of the learners with the learning environment (Price et al., 2012; Scruggs & Mastropieri, 2007). These barriers are not limited to the physical component, but also include cognitive, affective, language and socio-cultural aspects (Stinken-Rösner & Abels, 2021; Stinken-Rösner et al., 2020). Only if teachers are aware of these barriers and obstacles are they able to minimize them, what constitutes a prerequisite for participation.

Including all learners in education is a human right (UNESCO, 2005) that is not fulfilled by only refraining from external differentiation. Realizing inclusive education means to enable active participation in joint learning opportunities for all learners (Booth, 2003; Booth & Ainscow, 2016). To enable this, differentiated and individualized learning opportunities that differ in learning goals, contexts and methods are required (Stinken-Rösner et al., 2020). The matching of a learner's individual learning conditions and the learning environment essentially determines whether a learner is able to participate or not. In this regard, participation should be enabled by changing the learning environment rather than the learner (Meyer et al., 2013; Price et al, 2017).

2.2 Tasks in Inclusive Science Education

Tasks are central elements of teaching-learning processes as they prompt learners to engage with the learning content and transfer their knowledge and skills to new contexts (Reusser, 2013; Stäudel, 2003; Thonhauser, 2008). Commonly, tasks are constituted of two parts: the setting of the task and the work order. The setting frames the task, presents the context and provides the necessary materials. The work order (instruction) describes – more or less detailed – what the students are asked to do (Leisen, 2006). Tasks always comprise any kind of call to action that prompts students to interact with the object of learning by performing certain activities (Bruder, 2000; Jatzwauk et al., 2008; Leisen, 2006; Parchmann & Bernholt, 2016; Tepner, 2008). In this way, students' role is changed, from passive consumers (as it is usual in teacher-centered approaches) to active players. As a result, tasks have the potential to manifest students' level of learning as they make apparent how students cope with the requirements set in the task and to what extent they are able to work on the task independently.

Depending on the focused learning goal (*reasoning about scientific issues*, *learning scientific content*, *doing science* or *learning about science*; section 2.1), students are asked to perform specific activities that require conceptual, procedural, epistemic and/or social knowledge and skills (Furtak et al., 2012). Being not able to fulfill a task does not necessarily mean that students do not possess the required knowledge and skills, it might also indicate that they cannot follow the instructions or are excluded from learning because of barriers contained in or emerging from the task.

Doing science, particularly conducting experiments, has a major role in science education. Real-world experiments are carried out in up to every second physics and chemistry and every tenth biology lesson (Stinken-Rösner, 2020). Due to their strong presence in science education, it is of major relevance to explore how tasks connected to *doing science* can contribute to creating inclusive learning opportunities.

For this purpose, we review tasks – in particular those connected to *doing science* (Fig. 2) – for both conducive and hindering factors by addressing the three central aspects of inclusive pedagogy (section 2.1) one after another in the following section.

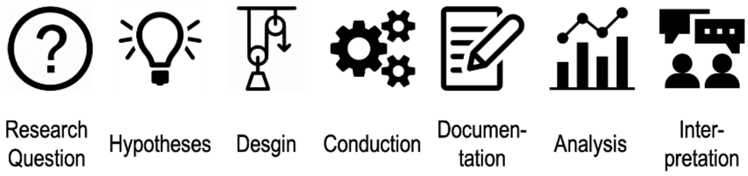


Fig. 2. The seven phases of inquiry when *doing science*: formulation of research question, generation of hypotheses, experimental design, conduction of the experiment, documentation, analysis and interpretation of the results (Nawrath et al., 2011).

2.2.1 Acknowledging Diversity

Depending on type and nature, tasks have the potential to address students' diversity by providing a basis for differentiated or even individualized learning environments (Dumont, 2019). In the aforementioned meaning of inclusive science education, *acknowledging diversity* means to respect students in their individuality, what implies to provide tasks that allow for diverse ways of engagement and learning. Especially so called *Lernaufgaben* can allow students to pursue their individual learning pathways and work at their own pace (Bönsch, 2012; Leisen, 2006; Reusser, 2013; Rieck, 2011). According to Florian and Spratt (2013), tasks should foster cooperative activities in which all students can introduce their individual resources and benefit from each other.

Due to its action-orientation as well as opportunities for differentiation and collaboration, *doing science* offers various approaches for all learners: from guided inquiry, where students follow given experimental instructions to reproduce results, to open inquiry of individual research questions (Blanchard et al., 2010; Hofer & Puddu, 2020). Also, materials can vary from everyday materials to professional lab equipment, depending on the previous experiences and fine-motoric skills of the students.

Designing tasks (not only) for *doing science*, teachers should consider students' individual potentials instead of their deficits (Abels, 2019).

2.2.2 Recognizing Barriers

Looking at a task, barriers can emerge from both, the task itself (setting and work order) and the interaction of students with this task.

The following are some of the aspects that can be affected by barriers:

- **Context**: *What is the task about?*
  By context, we mean the integration of subject content in relation to everyday life. This can be realized by the description of (natural) phenomena, situations, experiences etc. or by the formulation of questions or problems (van Vorst et al., 2015).
- **Activities**: *What has to be done in the task?*
  Are the activities defined and/or predetermined within the work order or have the activities been selected by the students? Are the activities described in the form of direct instruction or is the task formulated in a rather open way?
- **Accessibility**: *In what form is the task accessible to the students?*
  Are work order and material provided in oral, written, visual, aural, audiovisual or haptic form? Are the former accessible analogously or digitally?
- **Conditions**: *How has the task to be fulfilled?*
  Do students need to master the task individually or is it allowed to work with a partner or in a group? Is supportive material provided or do students need to work on the task without help?
- **Documentation**: *How has the task to be documented?*
  Is there any form of documentation required? Are there any guidelines students need to follow? Is the process of documentation pre-structured by materials such as worksheets, tables, templates etc.?

Regarding these aspects, there might arise cognitive, affective, language, social and cultural as well as physical barriers (Stinken-Rösner et al., 2020).

Cognitive barriers can be elicited by a context itself (especially for contexts referring to abstract or complex scientific concepts) or by alternative conceptions students hold about this context (Driver, 1989; Gropengießer & Marohn, 2018). Moreover, cognitively demanding forms of instruction (comprehensive, unstructured tasks) or complex activities can represent obstacles for learning.

Typical activities prevalent in tasks connected to *doing science* are e.g., formulating research questions and hypotheses, generating sketches or tables, analyzing and interpreting data as well as presenting findings graphically, verbally or in written form. All of these tasks strongly rely on reading, writing, drawing and mathematical skills, the consequence being that not all students are able to participate in these learning opportunities – some of them may be excluded completely.

According to Vygotsky (1978), tasks are most effective when they are located in students' *zone of proximal development*. This zone comprises tasks that students are able to fulfill when making use of supportive measures. In this way, students are prevented from both cognitive overload and cognitive underload. Cognitive over- and underload can also be the reason for lacking motivation – an *affective barrier* to learning (Deci & Ryan, 2008). Interest is another component that crucially influences students' learning. When choosing contexts for tasks, teachers should be aware that students' interest is strongly dependent on their cultural and socio-economic background, their age and gender (*general interest*; Jansen et al., 2016) as well as the way the context is framed (*situational interest*; Habig et al., 2018; van Vorst et al., 2015). Especially contexts that are strongly connected to scientific concepts and are considered being irrelevant or remote from everyday life may be barrier-loaden. Creating tasks connected to interdisciplinary contexts or providing possibilities to choose can help to address students' diverse interests and backgrounds, thus avoiding *affective barriers* as well as *social and cultural barriers* (Hartinger, 2006; Krapp & Prenzel, 2011; Kuhn & Müller, 2014).

Associated with students' diverse backgrounds – but by no means limited to – *language barriers* can make it significantly more difficult for students to work on tasks. Particularly, tasks connected to *doing science* require comprehensive reading and writing skills. Experimental instructions are mostly given in written form and use complex formulations (e.g., passive and impersonal) and scientific terms. Beyond that, students are asked to create a written documentation of the task in most cases: writing down their research questions and hypotheses, labelling detailed sketches of their experimental setup and/or describing this setup in words as well as documenting their observations or measurements in written form. Many students will potentially have difficulties to fulfill these tasks. For one thing, many students have problems in reading and/or creating longer passages of text and for another thing, the formal language and specific terminology of science is quite unfamiliar to students (Markic & Childs, 2016; Wellington & Osborne, 2009).

And finally, there might arise *physical barriers* from tasks. In the context of science education, especially tasks addressing the goal *doing science* are at risk to exclude students from learning. Labs are often equipped with inflexible mobiliary, which mainly allows for teacher-centered learning activities. Potentially dangerous materials (e.g., laser, scalpels or glass beakers), harmful substances as well as complex experimental setups represent further physical barriers (Stinken-Rösner & Abels, 2021).

2.2.3 Enabling Participation

Developing tasks for inclusive science education means to acknowledge students' diversity (section 2.2.1), to recognize potential barriers of these tasks (section 2.2.2) and to create a setting and work order that enable participation for all learners. One possibility to systematically develop inclusive tasks for science education is to apply the *Framework for Inclusive Science Education (FISE)* (Brauns & Abels, 2021). This framework arose from a systematic literature review and consists of 16 categories and numerous subcategories comprising suggestions on how to create learning environments for inclusive science education. These suggestions incorporate the aspects and barriers described above.

Following the *Framework for Inclusive Science Education* (Brauns & Abels, 2021) tasks connected to *doing science* can be created inclusively by allowing for various alternative approaches. One approach, which is in line with the first goal of science education as presented in Fig. 1, is to *create inclusive scientific contexts* (Brauns & Abels, 2021). Contexts, addressed in inclusive science education must be relevant and stimulating for all learners (Stinken-Rösner et al., 2020). In order to choose a context, teachers can draw e.g., on individual interests or previous experiences of the learning group. Also, fascinating (natural) phenomena can be used to create a stimulating context for all learners (Höft et al., 2019). Note, that a phenomenon can be used as context, as done in section 3. However, not every context necessarily refers to a natural phenomenon (cf. section 2.2.2). Also, contexts can be implemented differently in science education, as illustrative context, as connecting context, as central context, or as context on distance (Bruning & Michels, 2013).

Referring to tasks typically connected to the phases of inquiry (Nawrath et al., 2011; Fig. 2), Brauns and Abels (2021) present alternative, theoretically and empirically derived, approaches for:

- *creating inclusive generation of hypotheses and research questions,*
- *creating inclusive application of scientific research methods,*
- *creating inclusive scientific documentation,*
- *creating inclusive data evaluation and result presentation.*

For example, the formulation of research questions and hypotheses can be supported in terms of material, linguistic, cognitive, and communicational support or by allowing for different degrees of openness and levels of requirement (Hofer & Lembens, 2018). Scientific research methods, documentation, data evaluation, and result presentation can be supplemented by the use of digital media, e.g., by using digital measurement devices like internal and external measuring sensors, audio/video documentation or automated data representation and evaluation. Also, open learning approaches with self-determined processes and differentiation through different levels of abstraction, degrees of openness, or levels of requirements can enable students to engage with the same context (Abels, 2015).

3 Methods

In order to design a learning environment, which fosters *scientific literacy for all* while fulfilling the demands of inclusive pedagogy, it is first mandatory to identify a scientific issue or context that is addressing all learners (Stinken-Rösner et al., 2020, Fig. 1, upper left green hub; section 2.1). The chosen context as well as the corresponding learning goal(s) are analyzed in terms of relevance (section 3.1.1), possible barriers (section 3.2) and alternative approaches, which might give all learners the chance to participate (section 3.3).

For each of the idealized seven phases of inquiry (Nawrath et al., 2011, Fig. 2), tasks were identified, checked for possible barriers, and suggestions on how to enable participation for all learners were derived in accordance to the *FISE* (Brauns & Abels, 2021).

Following the design-based research approach (Collins et al., 2004), the learning environment was implemented during three consecutive years in the course of an introductory seminar on inquiry-based learning. In all, more than 100 pre-service teachers investigated the 'Flaschentuten' phenomenon in a lab session that lasted an hour and a half each. After each session, participants gave verbal feedback on their experiences. Special emphasis was placed on the barriers they faced in completing each task. Additionally, open observations during each session as well as authentic artefacts (e.g., (virtual) lab protocols) built the data base for the re-design of the learning environment. In the first year, exclusively traditional task formats connected to *doing science* were used, such as sketching the experimental setup, recording measurements in a table, or writing a lab protocol. During the following years of implementation, the learning environment was continuously developed further and barrier-loaden tasks were re-designed following the *FISE* (section 3.3).

3.1 The Context 'Flaschentuten'

The German term 'Flaschentuten' describes the sound that occurs when blowing over a bottle neck. By using differently sized bottles and/or filling levels, various sounds can be generated. In general, the higher the filling level, the higher the frequency of the resulting sound. The phenomenon 'Flaschentuten' can be applied in manifold ways in science education: e.g., to *learn scientific content*, to *do science* or in interdisciplinary approaches cooperating with musical education. Traditionally, musical instruments such as flutes or organs are used as illustrating contexts in science education. This means, the context is used as ad hoc illustration of scientific concepts already chosen (Bruning & Michels, 2013), which implies a dominance on *learning scientific content* in the corresponding lesson.

In the following, we will present how the phenomenon 'Flaschentuten' can be used as central context (Bruning & Michels, 2013) for planning an inclusive science lesson which fosters students to *do science* and allows for inclusive task formats.

3.1.1 Relevance of context

The context 'Flaschentuten' in itself has a rather low daily, scientific and subject-related relevance. Nevertheless, it is a fascinating and fun phenomenon for many learners. Students' situational interest can be triggered by a demonstration of the phenomenon in the classroom or by using newspaper articles about 'Flaschentuten' concerts or digital resources such as videos, in which popular songs are performed on bottles. In our experience, especially famous songs played on bottles are particularly fascinating and stimulating for learners of all ages. Participants show a high motivation to interact practically with the phenomenon.

Thus, even if the context 'Flaschentuten' has a rather low relevance, it raises students' situational interest and motivation to investigate the phenomenon practically and is therefore, in our opinion, best suitable to engage students in *doing science*. However, it is crucial to design the learning environment in such a way that it contributes to the development of *scientific literacy for all* and fosters selected learning goals.

3.2 Barriers of the context

In this section we will discuss typical barriers and challenges which occur when investigating the 'Flaschentuten' phenomenon. In order to design non-discriminating learning environments, it is important for teachers to be aware of these barriers, which can result from the interplay between the learner and the learning environment (Stinken-Rösner et al., 2020).

Acoustics is an essential part of physics education, which is not only challenging for hearing-impaired students. Due to its complexity, high level of abstraction, and use of specific scientific terms, acoustics is a barrier-loaden topic for many learners (section 2.2.2). For example, students are not familiar with scientific terms such as *wavelength*, *frequency* and *amplitude*. In daily life, sound is described either by using notes, e.g., when learning an instrument, or verbally (volume: quiet/loud and pitch: low/high), whereby especially younger children are struggling to distinguish between pitch and volume and using the correct terms for each (Wodzinski & Wilhelm, 2018).

The propagation of sound through air as longitudinal wave is a complex content, which is hard to understand for many learners. Same is valid for stationary waves, as in case of 'Flaschentuten'.

Common alternative conceptions are:

- sound propagates through space and returns to its source,
- sound does not need a medium to propagate in space,
- sound is damped by air and cannot propagate through a solid medium,
- musical instruments have holes so that sound can get out (sound passes through holes) (Wodzinski & Wilhelm, 2018).

The understanding of sound as a wave, which propagates through air, corresponds to a high level of abstraction. Sound waves are not visible, only hard to imagine and complex to describe mathematically. Therefore, the underlying content itself can be a cognitive barrier for learners.

Also, measurement, documentation and comparison of different sounds can be challenging. As the human ear is able to detect sounds ranging from 1000 to 2000 Hz with a resolution of 3.6 Hz (Olson, 1967), hearing-impairments can affect the individual sensory perception (physical barrier). Moreover, measurements based on sensory perceptions are always of qualitative nature and hard to document. Even if one is able to compare two successive sounds qualitatively in terms of volume and pitch, this becomes almost impossible for a complete measurement series. There is also the question of how to document one's own sensory perceptions (in written form) in a way that is understandable for someone who did not experience the same perception.

In contrast, the use of laboratory devices in order to measure sound quantitatively requires a basic knowledge of how to use the equipment and of the units in which sound is measured. Translating a certain sound into numbers and vice versa is a challenge for most people, since this is almost never practiced in daily or professional life. This results in a stalemate: On the one hand, qualitative observations are easier to perform but harder to document and to comprehend, quantitative measurements, on the other hand, are harder to perform but easier to document and comprehend.

Additionally, students need well developed fine motoric skills in order to “play” the bottle. Just as with whistling, some are more skilled than others.

3.3 Enabling Participation

In this section we demonstrate different approaches to design tasks, which allow all students to participate in investigating the context ‘Flaschentuten’. Barrier-loaden tasks connected to the investigation of the ‘Flaschentuten’ phenomenon were identified based on open observations during each session, subsequent verbal feedback from participants, and authentic artefacts such as (virtual) lab protocols (section 4). Subsequently, these tasks were re-designed according to the *FISE* (Brauns & Abels, 2021) to minimize barriers (section 3.3.1).

We chose the context ‘Flaschentuten’ since learners can engage practically with this phenomenon even with no to little knowledge about the underlying scientific content (e.g., origin and propagation of sound). Students can reproduce the phenomenon, observe and interact with it, ask questions to it, plan investigations around it, manipulate selected variables, document resulting sound variations, identify relations between variables, and present their findings to peers. The context engages learners to apply scientific methods and is therefore, in our opinion, best suitable to foster *doing science.* Using it instead as ad-hoc illustration in order to *learn scientific content* is possible but less beneficial, since the potential of the context is not exploit.

Depending on students’ previous level of expertise, the interaction with the context ‘Flaschentuten’ can vary in complexity. Students can engage with the context in accordance to their individual potentials, e.g., in terms of content knowledge, previous experiences, practical (lab) skills or personal interests.

3.3.1 Design of Inclusive Task Formats

Following the *FISE* (Brauns & Abels, 2021), various inclusive task formats were developed to enable participation for all learners while engaging practically with the context ‘Flaschentuten’.

We focused on three typical tasks that presented particular barriers for learners during the initial implementation of the learning environment (section 3.2): the *generation of research questions and hypotheses*, the *application of scientific research methods* and the *documentation of observations and/or measurements* (Brauns & Abels, 2021; Nawrath et al., 2011).

Following the inquiry-based learning approach, research questions can be generated with various degrees of openness (Blanchard et al., 2010; Hofer & Puddu, 2020; National Research Council, 1996). Either students address their own questions to the context ‘Flaschentuten’ (open inquiry) or work on questions given by the teacher (guided inquiry) (Blanchard et al., 2010). Depending on their level of expertise, students can formulate questions which fit to their previous content knowledge (“*What do I not know yet?*”) and/or to their practical skills *(“What can I investigate with/by…?”)*. This process is supported in different ways: communicatively in partner work and plenary (“*Which questions do we have to the video?*”, “*What is interesting to investigate?”, “What can we investigate with the given materials?*”), linguistically with pre-formulated sentence beginnings (“*How does the pitch/volume change with […]?*”) or cognitively by assigning images and materials to the corresponding terms (presentation of materials, which can be used to investigate one’s research questions). Accordingly, the formulation and documentation of hypotheses is supported verbally (“*The bigger/higher/smaller/lower/etc. the […], the higher/lower the resulting pitch*.”) and visually (Fig. 3).

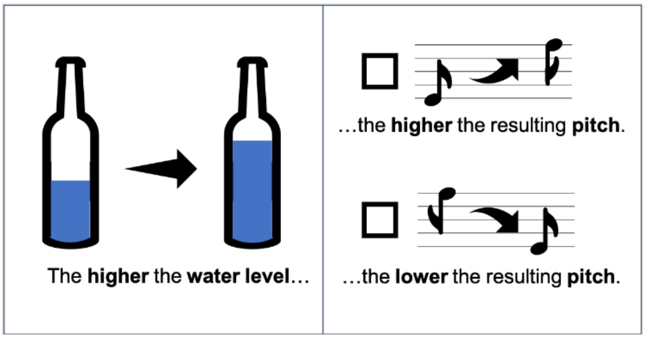


Fig. 3. Formulation of hypotheses with verbal and visual support. Students can indicate their hypothesis by checking the corresponding box on the right side.

Students need to choose one(!) research question in their respective group. Here, the identification of the independent and the dependent variable is central. Teachers can scaffold this process by asking students to verbalize or to demonstrate on the materials what (independent variable) they want to change in their experimental setup and which changes (in the dependent variable) they expect. For example, students may want to investigate how the pitch changes by using differently shaped bottles. By asking what "differently" means, students' attention is drawn on the characteristics of bottles (e.g., color, material, shape, volume, height, diameter of the bottle neck etc.) so that they can refine their question.

After having decided on a research question and having formulated a corresponding hypothesis, students plan their experimental setup. They decide which materials are used, how measurements are conducted and how results are documented. To enable participation for all learners, a variety of different materials is offered, ranging from household materials to laboratory equipment. Additionally, students choose between different techniques to analyze differences between pitches: by their sensory perception, by measuring sounds in terms of wavelength, frequency or note, or by using a visual representation of the sound wave. This can be done with laboratory equipment or with mobile devices (section 3.3.2; Fig. 4). By offering materials and measurement devices with varying complexity, students design their experimental setup accordingly to their prior knowledge and skills. They either work with materials they are familiar with or explore new ones.

Also, the level of complexity while conducting the experiment can vary between student groups. Students from one group can explore their research question already by comparing two sets of measurements with their sensual perception while others can record a high number of measurements with only small variations in the independent variable with lab devices. Allowing this, students can engage with the phenomenon at their own speed due to the varying complexity of the experimental setup and the acquisition of measurements. In contrast, by expecting all students to apply the same experimental methods with the same accuracy, some students will be under- and some overchallenged.

Furthermore, documentation was re-designed consistently to match the demands of inclusive science education. In addition to traditional paper-pencil lab reports, multiple alternative approaches are offered: verbal documentation in form of audio recordings, partial sketches of bottles and note lines (Fig. 3) where students can document their experimental setup and measurements visually as well as the use of cameras and microphones (integrated in mobile devices) to take pictures, audio or video recordings.

3.3.2 Digital Media Support

The re-design of tasks in order to allow for multimodal approaches when engaging with the context 'Flaschentuten' is supported by digital media. It makes little sense to translate digital artefacts, such as pictures of the experimental setup or measurements taken with mobile devices, into paper-pencil lab reports. Rather, new (digital) documentation formats need to be introduced which are in accordance with multimodal measurement and documentation approaches.

It is important to choose these digital tools carefully, since students can easily lose track of the actual learning goal while exploring the digital tools themselves (Abels & Stinken-Rösner, 2020). Only when choosing (an) adequate (combination of) digital tools can the learning process be optimally supported.

In the presented learning environment, each student group is provided with a tablet. An app to take sound measurements by using the sensors of the mobile device (*phyobox*; RWTH Aachen University, 2021) and a virtual bulletin board app (*padlet*; Wallwisher, Inc., 2021) are already preinstalled on all devices. Additionally, students can take pictures or videos and audio recordings by using the integrated microphone and camera of the device.

3.4 'Flaschentuten' as virtual learning lab during COVID-19

Due to the COVID-19 pandemic, we were faced with the challenge of how students can practically engage with the context 'Flaschentuten' at home. Most parts of the learning environment were easily adaptable to distance learning, for example, the demonstration of the phenomenon in form of an online video, the use of the virtual bulletin board as platform to document the research question, hypotheses, experimental setup, measurements as well as taking measurements with private mobile devices. More difficult, however, was the lack of experimental materials and laboratory equipment at home. This limited the variety of possible research questions. Also, students did not have access to professional laboratory equipment.

Nevertheless, our goal was to design a mixed-reality learning environment where students can access all necessary materials online while conducting their experiments in reality.

For this purpose, all previously existing materials were embedded in a virtual lab created with *Thinglink* (Thinglink Oy, 2021). Additionally, a videoconference software (*zoom;* Zoom Video Communications, Inc, 2021) was used to communicate with students as well as for group work in *breakout rooms*.

After a brief introduction to the structure of the virtual lab, students explored the context 'Flaschentuten' in small groups. The virtual lab served to guide the experimental process at home as well as to document the conducted experiments collaboratively online. During the lesson, the teacher supported the learning process by asking questions and providing guidance in form of conversations with students in the breakout rooms and/or by using the comment function of the virtual bulletin board.

4 Observations

The following observations on how learners engage with the context 'Flaschentuten' and the inclusively designed tasks are based on three years of experiences. In total, over 100 pre-service teachers investigated the 'Flaschentuten' phenomenon in the course of an introductory seminar on inquiry-based learning. None of the participants was enrolled in physics study programs at university level. Some already had experience with the context, but none was able to explain the phenomenon scientifically.

During these years, the learning environment (tasks and materials) was continuously improved in order to enable participation for all learners. The main differences in-between years are: In the first year, documentation was completely done paper based, in the second year, the virtual bulletin board was implemented to allow for alternative, multimodal (digital) documentation forms. An overview of the re-design process between year one and two is presented in Tab. 1. In the third year, the learning environment and existing tasks were adapted to distance learning and structured using a virtual learning lab (section 3.4).

Tab. 1. Enabling participation by re-design of typical tasks connected to *doing science*.

Typical tasks connected to *doing science*	Inclusive approach for the re-design according to the *FISE*
Generation of research questions and hypotheses	• communicatively (group work, asking comprehension questions, and use of comment function) • based on linguistic support (pre-formulated sentences, given sentence beginnings) • addressing different senses (pictograms and check-boxes) • materially guided (material table)
Application of scientific research methods	• addressing different senses (visually, acoustically, tangibly) • materially guided (choice between everyday objects and lab equipment) • digitally (measurement app) • at different levels of abstraction (creating transitions between frequency, period, pitch and visualization of sound wave)
Documentation of observations and/or measurement	• digitally (virtual lab report) • materially guided (given structure of virtual lab report) • at different levels of abstraction (documentation with audios, pictures, videos, text, tables) • addressing different senses (visually, acoustically)

Students' engagement with the context 'Flaschentuten' and their use of the re-designed tasks are discussed below.

4.1 Engagement with the Context

The context 'Flaschentuten' has proved to foster students' situational interest. Especially videos, in which popular songs are performed on bottles, resulted in a high motivation. After watching the video, students wanted to reproduce and explore the seen/heard phenomenon practically. At this point, it is important that the teacher guides and supports students in planning a systematic investigation. Otherwise, there is a risk that students will manipulate multiple variables randomly at the same time.

In our experience, some students struggled to identify and focus on one specific independent variable, which resulted in unprecise research questions and/or inadequate choice of materials ("different bottles"). Scaffolding (Hammond & Gibbons, 2005) in terms of asking comprehension questions as well as comparing different bottles and filling materials in terms of their characteristics helped these students to specify their question.

Generally, all students were able to ask questions to the phenomenon with little assistance. Typically occurring research questions were related to (i) the characteristics of the bottle, (ii) the filling level, (iii) the filling material and (iv) the way the bottle is "played":

(i) *How does the pitch change with the shape of the bottle (in terms of volume, height or diameter (of the bottle neck), thickness of the bottle wall etc.)?*
(ii) *How does the pitch change with the filling level? How does the pitch change with the air volume inside the bottle? How does the pitch change with the air/water ratio inside the bottle?*
(iii) *How does the pitch change with the filling material (different viscosity, phase state etc.)?*
(iv) *How does the pitch change with the air stream above the bottle neck (in terms of velocity, angle etc.)? How does the pitch change with the distance between the blowing person and the bottle?*

The dependence of the pitch on an independent variable was central to all of these questions. Students rarely addressed the volume of the pitch. Almost automatically, the investigation of the context 'Flaschentuten' implied an application of the variable control strategy, which is a fundamental procedure for *doing science*.

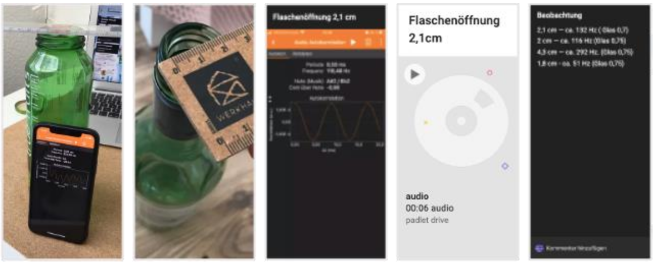
In our experience, most students were able to choose and conduct an experiment accordingly to their individual research question. Usually, the complexity of the research question and the conducted experiment matched students' previous knowledge and skills. Nevertheless, it is important that teachers pay attention to the respective approach. Some learners tend to choose the easy way. This means, they collect only a minimal number of datasets and/or favor qualitative observations instead of quantitative measurements. By applying techniques, they are experienced in, to new situations, only little improvement of their practical skills is achieved. Targeted scaffolding by the teacher, e.g., in form of material suggestions, introductions in measurement devices or measurement units can contribute to ensure learning in the *zone of proximal development* (Vygotsky, 1978; cf. section 2.2.2). We did not observe that students were overchallenged by investigating their own research questions – which does not mean that this can be ruled out.

4.2 Use of Inclusive Task Formats

While engaging with the 'Flaschentuten' phenomenon, students could choose between a variety of materials, measurement devices and documentation forms (section 3.3) in order to enable participation for all learners. The majority of students made use of these offers, in particular the measurement app and the alternative digital documentation forms were frequently used.

Students felt comfortable to measure the pitch by using a mobile device. The app determines the frequency and period of the sound. Additionally, the correlating note and a visual representation of the sound wave are shown. Depending on their previous knowledge, students used either the frequency or the note to describe the pitch. Interestingly, students who had a musical background, tended to use notes, while students with no prior knowledge on units in which the pitch can be described chose to record their measurements in terms of frequency. This was used by the teacher to initiate a discussion about common measurement units and unit conversions.

Additionally, the implementation of the shared virtual bulletin board as alternative type of protocol was very popular among learners. Each group was assigned one column of the board beforehand, where they collected their research questions and hypotheses, pictures of their experimental setup, screenshots of the measurements, audio recordings, as well as written summaries and conclusions (Fig. 4).



Flaschenöffnung 2,1 cm

Flaschenöffnung
2,1cm

audio
00:06 audio
padlet drive

Beobachtung
2,1 cm – ca. 132 Hz (Glas 0,7)
2 cm – ca. 116 Hz (Glas 0,75)
4,3 cm – ca. 292 Hz. (Glas 0,75)
1,8 cm - ca. 51 Hz (Glas 0,75)

Fig. 4. Extracts from the virtual bulletin board of a group which investigated the relationship between the diameter of the bottle neck and the resulting pitch. From left to right: Picture of the experimental setup, visual documentation of the independent variable (bottle neck diameter), screenshot of the measurement (dependent variable: pitch), audio recording of the pitch and written summary of the measurement results.

Although groups worked on different questions, in the end, a shared knowledge base was available to all of them. Students explored the work of other groups, asked questions and discussed different approaches and findings. Even though this was not foreseen in the re-design of the learning environment, *learning about science* and especially the comprehensible documentation of experiments became central.

Note, that not all students have previous experiences with the use of virtual bulletin boards. In our experience, students tend to use the virtual bulletin board for written notes. Only after having pointed out additional features, such as inserting pictures or recording audio files, they made use of these alternative documentation formats.

5 Discussion and Conclusions

In this article, we made an attempt to re-think tasks in science education so that they allow participation for all learners, thus meet the requirements of inclusive pedagogy. Referring to the context 'Flaschentuten', we explored how tasks connected to *doing science* (generation of research questions and hypotheses, application of scientific research methods, documentation of observations and/or measurements) can be designed inclusively by providing various alternative approaches and applying supportive measures.

The observations from three years of experiences when implementing the context 'Flaschentuten' in an introductory course on inquiry-based learning show that this originally barrier-loaden context (cognitive and physical barriers) can yet allow participation for all learners (in this case: pre-service teachers). Even though the context is of low daily and scientific relevance, learners' situational interest can be aroused, e.g., by introducing fascinating videos, so that learners are willing to engage with the context. By focusing on the learning goal *doing science*, main cognitive barriers – the complex and abstract concepts in the field of acoustics – can be removed. This only works, of course, when selecting a context that allows for investigations even when learners have not captured the underlying scientific concepts.

Beyond that, providing multimodal approaches allows students to participate considering their individual learning conditions (e.g., sensory perception) and prior experiences (e.g., from playing an instrument). Implementing digital media can provide alternative approaches that increase the possibilities of participation when conducting investigations (e.g., qualitative and quantitative measurements) and documenting the experimental setup and results (e.g., photos, screenshots, audio recordings). Moreover, using digital documentation tools can foster the collaboration between learners (e.g., when discussing joint results) and provide access in distance learning-settings as well.

It became apparent that scaffolding is a crucial element of inquiry-based learning even when learners already have fundamental prior knowledge and skills regarding scientific content and procedures (Hmelo-Silver et al., 2007; Jiang & McComas, 2015). Also, the use of digital media needs to be supported in order to focus students' learning and exploit the full potential of tools (e.g., including pictures and audio recordings in a virtual bulletin board).

According to the sample of our study, results have to be seen as both explorative and limited to the group of pre-service teachers with prior knowledge and skills in science. However, none of them was enrolled in physics study programs – no one was able to explain the phenomenon in a scientifically correct way as well. Beyond that, many of the pre-service teachers had trouble applying the variable control strategy, similar as it is known from undergraduate students (Zimmerman & Croker, 2013).

In conclusion, the experiences made with the context 'Flaschentuten' show that re-thinking tasks from the perspective of inclusive science education can result in learning environments that enable participation for all learners. Applying frameworks, such as the *Framework for Inclusive Science Education* (Brauns & Abels, 2021), can help to identify potential barriers of contexts, tasks and materials for one thing and for another thing, it can serve as inspiration when looking for alternative approaches that are compatible with the requirements of inclusive science education.

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Supplementary Materials

The link to the virtual learning lab 'Flaschentuten' can be provided by the authors on request.

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