

Hagenkötter, Ramona; Nachtigall, Valentina; Rolka, Katrin; Rummel, Nikol
Learning mathematical modelling with experimental data from scientist and peer models. Transferring results on the perception of authenticity from a school setting to an out-of-school lab

Unterrichtswissenschaft 54 (2026) 2, S. 137-167



Quellenangabe/ Reference:

Hagenkötter, Ramona; Nachtigall, Valentina; Rolka, Katrin; Rummel, Nikol: Learning mathematical modelling with experimental data from scientist and peer models. Transferring results on the perception of authenticity from a school setting to an out-of-school lab - In: Unterrichtswissenschaft 54 (2026) 2, S. 137-167 - URN: urn:nbn:de:0111-pedocs-355280 - DOI: 10.25656/01:35528; 10.1007/s42010-025-00237-5

<https://nbn-resolving.org/urn:nbn:de:0111-pedocs-355280>

<https://doi.org/10.25656/01:35528>

in Kooperation mit / in cooperation with:



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Learning mathematical modelling with experimental data from scientist and peer models: Transferring results on the perception of authenticity from a school setting to an out-of-school lab

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Received: 15 March 2024 / Revised: 18 August 2025 / Accepted: 18 August 2025 / Published online: 17 September 2025
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Abstract Out-of-school labs (OSLs) are considered a promising opportunity to provide students with authentic experiences by engaging them in authentic activities that emulate the work of professionals of a certain discipline. However, such authentic learning activities may cognitively overwhelm learners and are often not perceived as authentic by students. Thus, the hypothesized positive motivational and cognitive effects of authentic learning are often not evoked. Therefore, the present paper focuses on providing students with first authentic and not too cognitively demanding insights into mathematical modelling with experimental data. We conducted a quasi-experimental study with 111 9th and 10th graders who observed a video of either peer or scientist models performing a mathematical modelling task with experimental data followed by conducting a similar task themselves in an OSL. We investigated the effects on students' perceived authenticity, situational interest, and knowledge acquisition. Thereby, we aimed to conceptually replicate a previous study that took place at the students' school, in an OSL. As found in our school study, students in the OSL perceived the scientist models more authentically than

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the peer models. In contrast, in the OSL study, students who observed peer models reported higher situational interest than students who observed scientist models. Our results further indicate differential effects on students' perceived authenticity during subsequent mathematical modelling with experimental data themselves. We discuss the results in light of previous research on learning in authentic contexts.

Keywords Authentic learning · Out-of-school learning · Video modeling examples · Model authenticity · Mathematical modelling with experimental data · Motivational and cognitive effects

Mathematisches Modellieren mit experimentellen Daten durch die Beobachtung von Wissenschaftler*innen und gleichaltrigen Schüler*innen lernen: Übertragung von Ergebnissen zur Authentizitätswahrnehmung aus einem schulischen Setting in ein Schülerlabor

Zusammenfassung Schülerlabore gelten als vielversprechende Möglichkeit, Schüler*innen authentische Erfahrungen zu ermöglichen, indem sie sie in authentische Lernaktivitäten einbinden, die die Arbeit von Fachleuten einer bestimmten Disziplin nachahmen. Allerdings können solche authentischen Lernaktivitäten Lernende kognitiv überfordern und werden oft nicht als authentisch von Schüler*innen wahrgenommen, weshalb die angenommenen positiven motivationalen und kognitiven Effekte authentischen Lernens oftmals nicht hervorgerufen werden. Der vorliegende Beitrag fokussiert daher darauf, Schüler*innen erste authentische und kognitiv nicht zu anspruchsvolle Einblicke in das mathematische Modellieren mit experimentellen Daten zu geben. Es wurde eine quasi-experimentelle Studie mit 111 Neunt- und Zehntklässler*innen in einem Schülerlabor durchgeführt, die in einem Video entweder gleichaltrige Schüler*innen oder Wissenschaftler*innen beim mathematischen Modellieren mit experimentellen Daten beobachteten und anschließend eine ähnliche mathematische Modellierung mit experimentellen Daten eigenständig durchführten. Die Auswirkungen auf die von den Schüler*innen wahrgenommene Authentizität, ihr situationales Interesse und ihren Wissenserwerb wurden untersucht. Dabei wurde eine frühere Studie, die an der Schule stattgefunden hat, im Schülerlabor konzeptuell repliziert. Wie bereits in der Studie in der Schule, nahmen die Schüler*innen die Wissenschaftler*innen authentischer wahr als die gleichaltrigen Schüler*innen. Im Gegensatz dazu berichteten im Schülerlabor die Schüler*innen, die gleichaltrige Schüler*innen beobachteten, ein höheres situationales Interesse als diejenigen, die Wissenschaftler*innen beobachteten. Unsere Ergebnisse zeigen außerdem unterschiedliche Effekte auf die von den Schüler*innen wahrgenommene Authentizität beim anschließenden eigenständigen mathematischen Modellieren mit experimentellen Daten. Die Ergebnisse werden vor dem Hintergrund bisheriger Forschung zum Lernen in authentischen Kontexten diskutiert.

Schlüsselwörter Authentisches Lernen · Schülerlabor · Beobachtungslernen · Authentizität der Modellpersonen · Mathematisches Modellieren mit experimentellen Daten · Motivationale und kognitive Effekte

1 Introduction

Out-of-school labs (OSLs) aim to trigger students' interest in and to enhance their knowledge about scientific ways of thinking and working (e.g., Scharfenberg and Bogner 2014). For this purpose, they aim to enable authentic experiences for students by placing them “in the role of a professional by providing them with access to the methods and tools that are typical for the work of professionals or that emulate certain processes and features of professionals' work in a specific discipline” (Nachtigall et al. 2022, p. 1484; see also, e.g., Scharfenberg and Bogner 2014). One key method of many empirical scientific disciplines, such as the natural sciences, is mathematical modelling (see, e.g., Niss 1994). It describes the process of solving real-world problems by transferring a real-world situation into a mathematical model which can be analyzed using mathematical methods and, thus, obtaining mathematical results which need to be translated back into reality (e.g., Blum and Niss 1991; Geisler and Rach 2023). Given that “experiments related to mathematics find their natural place in the framework of mathematical modelling because they represent the ‘rest of the world’ for which mathematical models are built” (Halverscheid 2008, p. 226), it seems particularly promising in order to enable authentic experiences for students to conduct the modelling process with self-measured data, for instance, gained through hands-on experiments, as a specific kind of mathematical modelling (e.g., Geisler 2021a, b; Geisler and Rach 2023; Zell and Beckmann 2009). However, mathematical modelling in general (e.g., Blum and Borromeo Ferri 2009; Blum and Leiß 2007) and mathematical modelling with experimental data in particular (e.g., Geisler 2021b) are challenging for many students due to its inherent cognitive complexity. A high level of authenticity is usually accompanied by a high level of complexity, which can be cognitively overwhelming for learners and, thus, hamper or even prevent cognitive learning outcomes (e.g., Nachtigall et al. 2024). Furthermore, previous research on students' perception of authenticity and its effects in OSLs indicates that students often do not perceive learning activities that emulate discipline-specific practices as authentic as intended and, thus, the hypothesized positive motivational and cognitive learning outcomes are often not evoked (e.g., Hohrath et al. 2024; Nachtigall and Rummel 2021; Nachtigall et al. 2018).

The present study therefore faces the fundamental challenge of developing a learning setting that is both not too cognitively demanding for learners and at the same time perceived as authentic by them, so that it achieves both motivational and cognitive effects. Based on the results of a study by Stamer et al. (2021) indicating that the implementation of videos of working scientists can foster students' perception of authenticity and convey an authentic conception of scientists' work in an OSL and in line with the example-based-learning-principle (e.g., van Gog and Rummel 2010; van Harsel et al. 2022), it seems particularly promising and not too cognitively demanding to provide students with first authentic insights into mathematical

modelling with experimental data by letting them observe corresponding video modelling examples followed by students modelling with experimental data themselves. However, while from a social-cognitive perspective of example-based learning (see, e.g., Bandura 1994; Buunk et al. 2003; Hoogerheide et al. 2016; Schunk 1987), models of the same age with similar expertise (i.e., peer models) seem be particularly conducive to learning, from an authentic learning perspective (see, e.g., Betz et al. 2016; Nachtigall et al. 2022), scientist models seem to be particularly suitable for conveying authentic experiences and, thus, for fostering motivational and cognitive learning outcomes. Therefore, the present paper aims to investigate the effects of observing models with different degrees of authenticity (i.e., peer models vs. scientist models) of mathematical modelling with experimental data in an OSL on students' perceived authenticity, their motivational (i.e., situational interest) and cognitive (i.e., knowledge acquisition) learning outcomes on the one hand (research objective (RO) 1) and students' perception of authenticity during subsequently performing a similar mathematical modelling task with experimental data themselves on the other hand (RO2). In doing so, the present paper aims to conceptually replicate (e.g., Schmidt 2009) and extend a previous study (Authors 2024a) comparing the effects of observing peer or scientist models of mathematical modelling with experimental data on students' perceived authenticity, their situational interest and their knowledge acquisition which took place at the students' school.

2 Theoretical background

2.1 Authentic learning in out-of-school labs

In order to trigger students' interest in and to enhance their knowledge about scientific ways of thinking and working, OSLs implement various design elements to create authenticity (see also, e.g., Nachtigall and Rummel 2021). For example, they often engage students in authentic activities that emulate the work of professionals of a certain discipline, such as hands-on experimentation activities, and are generally located at universities, larger research institutes, or industrial plants (e.g., Garner and Eilks 2015). In OSLs, students work in professional settings using materials and tools that are typically also applied by practitioners and are often instructed by experts (for more detailed characterizations of OSLs, see, e.g., Garner and Eilks 2015; Scharfenberg and Bogner 2014). Given that authenticity is a multi-dimensional construct (see, e.g., Betz et al. 2016; Finger et al. 2022), these different design elements to create authenticity can be classified into different dimensions that can be designed more or less authentically. For example, based on theoretical models of the perception of authenticity in science education, especially the model of authenticity in teaching and learning contexts from Betz et al. (2016; see also Fig. 1), Finger et al. (2022) empirically distinguished between the four authenticity dimensions instructor, location, method, and innovation. As further shown in the model, the different characteristics of a learning setting are assumed to interact with various personal characteristics of learners, such as their individual interest or their prior knowledge and experience. This interaction then is assumed to result in the

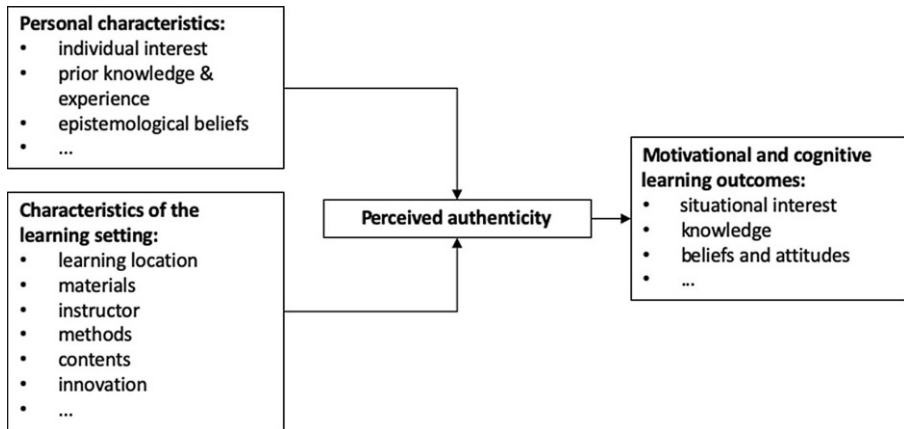


Fig. 1 Model of authenticity in teaching and learning contexts adapted from Betz et al. (2016, p. 816; see also Nachtigall et al. 2022, p. 1486)

perception of authenticity of the learning setting by students, which, in turn, may affect students' motivational (e.g., situational interest) as well as cognitive (e.g., knowledge acquisition) learning outcomes.

However, previous research on students' perception of authenticity and its effects in OSLs demonstrate that students often do not perceive authentic learning activities that emulate discipline-specific practices as authentic as intended and, thus, do not evoke the hypothesized positive motivational and cognitive effects (e.g., Hohrath et al. 2024; Nachtigall and Rummel 2021; Nachtigall et al. 2018). With regard to the hypothesized motivational effects, previous studies focused especially on students' *situational interest* which can be defined as "the psychological state of engaging or the predisposition to reengage with particular [...] content" (Hidi and Renninger 2006, p. 112). It is further assumed that situational interest is first triggered and then maintained through, for instance, external features of the learning setting. For example, the results of two studies by Nachtigall and colleagues (Nachtigall et al. 2018; Nachtigall and Rummel 2021) who varied the authenticity level of the method learners used to solve a given task or problem in an OSL for social sciences show that the intended authenticity level of the learning activity did neither affect students' perceived authenticity nor their situational interest. They further found that students' perceived authenticity correlated with their situational interest. With respect to students' *cognitive learning outcomes*, they did not find a correlation between students' perceived authenticity and their knowledge acquisition. Similarly, the results of a study by Hohrath et al. (2024) comparing self-determined experimentation as a highly authentic learning activity to guided experimentation as a less authentic learning activity in physics did not reveal a mediating effect of students' perceived authenticity of the method on their cognitive learning outcomes. In addition, their findings show that students who perceived the method as more authentic achieved higher learning outcomes.

In summary, these findings indicate that "authentic does not equal authentic" (Nachtigall et al. 2018, p. 300; see also, e.g., Barab et al. 2000; Gulikers et al. 2008),

which may have hindered the hypothesized motivational and cognitive effects of authentic learning. One possible reason for this could relate to different perceptions about authentic (i.e., professionally contextualized) practices between those who develop learning settings and the participating students due to students' often limited conceptions about science and scientific work (see, e.g., Nachtigall et al. 2018) as well as their lack of prior knowledge and experience (see, e.g., Hohrath et al. 2024). This seems to be especially problematic with regard to mathematical modelling with experimental data as an authentic learning activity.

2.2 Mathematical modelling with experimental data as an authentic learning activity

As mentioned above, *mathematical modelling* is considered a key component with great relevance for many empirical scientific disciplines (see, e.g. Niss 1994). According to, for example, the modelling cycle by Blum and Leiß (2007), mathematical modelling starts with a real situation which first has to be understood, leading to the so-called situation model. This situation model is a mental representation of the real situation which has to be simplified and structured focusing on relevant information into a real model. This real model has then to be mathematized by, for example, translating its data and relations into mathematics, resulting in a mathematical model of the real situation. By working with the mathematical model, mathematical results are obtained. These mathematical results have then to be re-translated into the real world by interpreting them in relation to the original real situation in order to obtain real results. These real results as well as the whole modelling process finally have to be validated with respect to the situation model. However, as, for instance, Engel (2010) criticizes, many modelling tasks in textbooks use unrealistic data which often already fit an intended model and, thus, validating one's own model becomes not apparent for students. Therefore, he argues that real data, which usually do not perfectly fit a mathematical model, are necessary for authentic modelling and to illustrate the relevance of validating the model.

One possibility to integrate real data in the modelling process is to combine modelling tasks with data which students gather through, for instance, hands-on experiments (e.g., Geisler 2021a, b; Geisler and Rach 2023; Halverscheid 2008; Zell and Beckmann 2009). Following Ludwig and Oldenburg (2007, p. 4; own translation), in the present paper, experiments are understood as “a planned and controlled action with objects, guided by hypotheses, for the purpose of gaining knowledge.” Based on the previously presented modelling cycle by Blum and Leiß (2007) as well as the mathematical experimentation cycle from Ganter and Barzel (2012) comprising the four phases assuming, planning, conduction, and analyzing, Geisler (2021a) developed an integrated model of *modelling with experiments* (see Fig. 2). Accordingly, hands-on experiments serve as a suitable starting point for mathematical modelling as they represent the “rest of the world” for which mathematical models are built (see also, e.g., Halverscheid 2008). The experiment itself, which always contains idealizations, can be considered a real model and the notation of the collected data (e.g., in a table) represents a first step of mathematization. Thus,

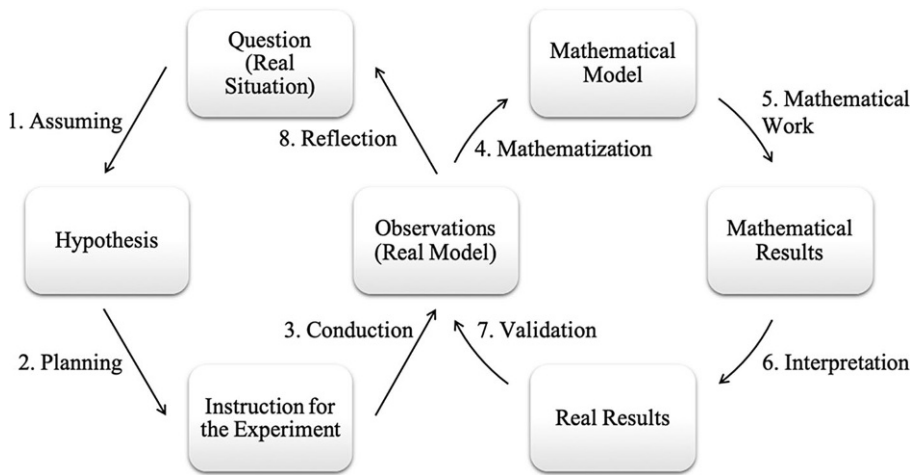


Fig. 2 Integrated model of modelling with experiments (adapted from Geisler 2021a, p. 205)

mathematical modelling with experimental data starts with a hands-on experiment and then the collected data is used for mathematical modelling.

More specifically, during mathematical modelling with experimental data, students often work together in groups and have to make assumptions, plan and conduct an experiment, deduct a mathematical model from the real world (e.g., by noting the measured values and transferring them to a coordinate system), answer mathematical questions within this mathematical model, interpret the mathematical results in the real situation, validate the solution, and reflect on their approach. By this combination, a natural link between mathematics and the natural sciences is established (e.g., Geisler and Rach 2023).

However, previous research reveals that mathematical modelling in general and mathematical modelling with experimental data in particular are challenging for many students. For example, Blum and Leiß (2007) observed, video graphed, and interviewed 9th graders solving modelling tasks in pairs and found that all steps in the modelling process represented cognitive barriers for students. In particular, they observed a lack of validation and substantial reflection at the end of the process by the students. In other words, students often did not check whether their solutions are reasonable and appropriate (see also, e.g., Blum and Borromeo Ferri 2009). Similar results were also found regarding mathematical modelling with experimental data in a study by Geisler (2021b). He also observed that many students struggled with the validation of their models and put more trust in their models than in their measured data during the experiment. As a result, they tend to improve the measurement during experimentation instead of revising their model in order to improve fit between model and experimental data. These difficulties may be ascribed to the fact that mathematical modelling and, especially, mathematical modelling with experimental data is rarely implemented in mathematics classes (e.g., Halverscheid 2008; Jordan et al. 2008) and, thus, students have no or only few experience. Beyond that, another reason why modelling is so difficult for students relates to the inherent

cognitive complexity and, thus, the high cognitive demands on students (e.g., Blum and Borromeo Ferri 2009). In mathematical modelling (with experimental data), students require various (mathematical) skills, such as reading and communicating, designing and applying problem solving strategies, or working mathematically, as well as understanding of both the mathematical content involved and the “rest of the world” for which the mathematical model has to be built.

Against this background, it seems to be necessary to reduce the cognitive demands on students in mathematical modelling with experimental data. However, a high level of instructional support may lead to a considerable reduction or even the loss of authenticity and, thus, hamper the positive motivational effects of authentic learning (e.g., Nachtigall et al. 2024). Therefore, in order to promote both students’ motivational and cognitive learning outcomes, it seems necessary to reduce the cognitive demands on students and, at the same time, foster their perception of authenticity in mathematical modelling with experimental data. Based on the results of a study by Stamer et al. (2021) as well as the example-based-learning-principle (e.g., van Gog and Rummel 2010; van Harsel et al. 2022), one promising way relates to the implementation of video modeling examples of mathematical modelling with experimental data followed by students modelling with experimental data themselves.

2.3 Implementation of video modeling examples of mathematical modelling with experimental data

According to the example-based-learning-principle (e.g., van Gog and Rummel 2010; van Harsel et al. 2022), observing “a model demonstrating and possibly explaining the solution procedure step by step on video” (van Harsel et al. 2022, p. 704; see also, e.g., van Gog and Rummel 2010) may reduce the cognitive demands on students. Furthermore, as the results of a study by Stamer et al. (2021) in an OSL reveal, implementing videos of working scientists can foster students’ perception of authenticity and convey an authentic conception of scientists’ work. Given these arguments, it seems to be particularly promising and not too cognitively demanding to provide students with first authentic insights into mathematical modelling with experimental data by letting them observe corresponding video modeling examples. Therefore, in a previous study (Authors 2024a), we have begun to examine the effects of observing models with different degrees of authenticity of mathematical modelling with experimental data¹ on students’ perceived authenticity as well as their motivational (i.e., situational interest) and cognitive (i.e., knowledge acquisition) learning outcomes. More specifically, we investigated how students perceive and learn from scientist and peer models of mathematical modelling with experimental data. On the one hand, from a perspective of authentic learning, the presence of experts, such as scientists, is considered being a design element of authentic learning settings (e.g., Nachtigall et al. 2022) which may foster students’ perception of

¹ Please note that we used the term “mathematical hands-on experimentation” for better readability in our previous paper (Authors 2024a), but still refer to the same, namely mathematical modelling with experimental data.

authenticity and, thus, their motivational and cognitive learning outcomes (e.g., Betz et al. 2016). On the other hand, from a social-cognitive perspective of example-based learning (e.g., Bandura 1994; Schunk 1987), it may be assumed that, especially for novices as they are particularly likely to engage in social comparison (see, e.g., Buunk et al. 2003; Hoogerheide et al. 2016), students of the same age with similar expertise (i.e., peers) may be particularly conducive to learning. As expected, our results show that students perceived the scientist models as more authentic than the peer models. Against the assumptions of authentic learning (e.g., Betz et al. 2016), we further found neither a direct effect of condition nor an indirect effect mediated by students' perceived authenticity of the observed models on students' situational interest and their knowledge acquisition. However, due to the covid-19 restrictions, that study took place at the students' *school*. The fact that the video modeling examples were shown in the students' own school as a less authentic location may have influenced the results.

With this in mind, the present study aims to, on the one hand, conceptually replicate (e.g., Schmidt 2009) our previous study in an OSL at a university as a highly authentic learning location and, on the other hand, extend the findings by adding a further learning phase in which the students perform a mathematical modelling task with experimental data themselves after observing the video modeling examples.

2.4 The present study

Like our previous study (Authors 2024a), the present study aims to investigate the extent to which observing models with different degrees of authenticity (i.e., peer models vs. scientist models) of mathematical modelling with experimental data affects students' perception of authenticity as well as their motivational (i.e., situational interest) and cognitive (i.e., knowledge acquisition) learning outcomes (research objective (RO) 1). In doing so, we investigated the same hypotheses using the same video modeling examples as well as the same or slightly adapted measures as in our previous study but changed the learning location (i.e., OSL instead of students' school). This is what, for example, Schmidt (2009, p. 96) refers to as *conceptual replication*: "Conceptual replications test hypotheses or results from earlier research with a different experimental set-up." Compared to a direct replication, which produces facts, a conceptual replication may create understanding as it also may corroborate the theory behind the hypotheses. Following the demands for changes and constants for a conceptual replication by Schmidt (2009), we kept the way how the independent variable is presented to the participants as well as the selection of participants constant. What we changed are especially the contextual background (e.g., general physical setting of the research) as well as slightly the material and the procedures used to constitute the dependent variables. Specifically, we again derived and investigated the following hypotheses (see Fig. 3):

Given that scientist models are likely considered more as experts than peer models, which is one of the design elements of authentic learning settings (e.g., Nachtigall et al. 2022), and the findings of Stamer et al. (2021) indicating that the observation of scientists can promote students' perception of authenticity, we hypothesize that students who observe scientist models of mathematical modelling with exper-

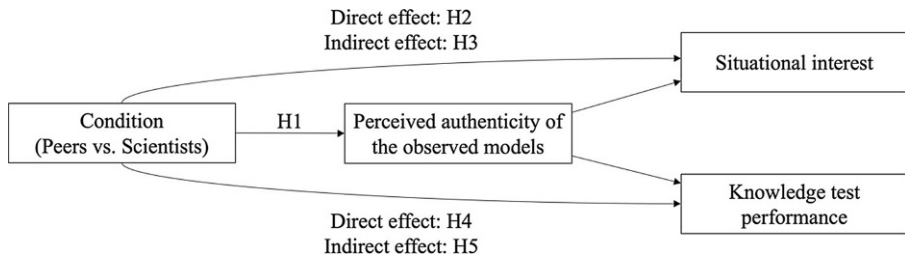


Fig. 3 Overview of the hypotheses

imental data will report higher *perceived authenticity of the observed models* than students who observe peer models (Hypothesis 1/H1).

Building on the model of authenticity by Betz et al. (2016; see Fig. 1), we assume that students who observe scientist models of mathematical modelling with experimental data will report higher *situational interest* than students who observe peer models (Hypothesis 2/H2) and that the effect of observing models with a different degree of authenticity on students' situational interest will be mediated by their perceived authenticity of the observed models (Hypothesis 3/H3).

Furthermore, with regard to students' *knowledge acquisition*, we derived the following contradictory hypotheses: From a social-cognitive perspective of example-based learning (see, e.g., Bandura 1994; Buunk et al. 2003; Hoogerheide et al. 2016; Schunk 1987), it can be assumed that students who observe peer models of mathematical modelling with experimental data will achieve higher knowledge acquisition (i.e., performance on a knowledge test) than students who observe scientist models (Hypothesis 4a/H4a). In contrast, from a perspective of authentic learning (e.g., Betz et al. 2016; Nachtigall et al. 2022), it can be hypothesized that students who observe scientist models of mathematical modelling with experimental data will achieve higher knowledge acquisition than students who observe peer models (Hypothesis 4b/H4b) and that the effect of observing models with a different degree of authenticity on students' knowledge acquisition will be mediated by their perceived authenticity of the observed models (Hypothesis 5/H5).

In addition, given that students' prior (knowledge and) experience may influence their perception of authenticity (e.g., Betz et al. 2016; see also, e.g., Hohrath et al. 2024), we further aim to extend our previous study by exploring to what extent observing models with a different degree of authenticity affects students' perception of authenticity when subsequently performing a similar mathematical modelling task with experimental data themselves (RO 2). For this purpose, we implemented a second learning phase (which was not part of our previous study) in which the students performed a similar mathematical modelling task with experimental data themselves in the OSL after observing either the peer or scientist models and subsequently assessed their perceived authenticity.

3 Method

In the present paper, we use data from a larger study on mathematical modelling with experimental data in an OSL with a different research focus. As the purpose of the present paper is to conceptually replicate and extend our previous study, here, we focus on a subsample, namely the students who observed either peer or scientist models performing a mathematical modelling task with experimental data in a video recording followed by conducting a similar mathematical modelling task with experimental data themselves.

3.1 Participants and design

Participants were 111 9th and 10th graders ($M_{\text{age}} = 14.72$, $SD = 1.02$, 44 female students, 62 male students, 5 diverse students) from seven classes of four secondary schools. As the study took place in an OSL at a large German university which is usually visited by whole classes, we implemented a quasi-experimental design and randomly assigned the whole classes to the *peer condition* ($n = 58$) and *scientist condition* ($n = 53$).²

3.2 Research context

The study was conducted in a day-long OSL project on exponential growth and decay processes which aimed at offering students first insights into exponential processes (in comparison to the already familiar linear processes). For this purpose, they investigated and modeled various everyday growth and decay processes in order to explore exponential processes. In doing so, students' abilities to differentiate between dependent and independent variables as well as to change between different types of representations of functions should also be promoted. Furthermore, by combining modelling tasks with experimental data which usually do not fit a mathematical model and, thus, illustrate the relevance of validating the model (e.g., Geisler 2021a, b), the OSL project further aimed to enhance students' validation skills.

3.3 Materials

3.3.1 Video modeling examples

The students in both conditions watched a 25 min video in which three people (two male and one female) performed a mathematical modelling task with experimental

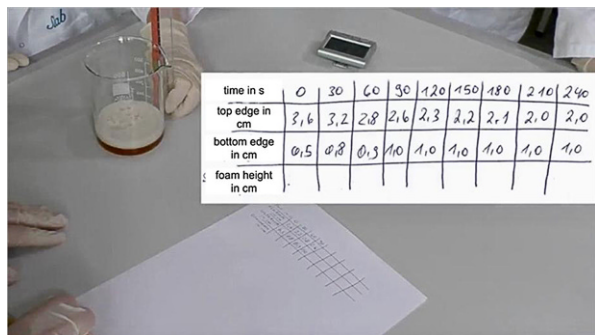
² Please note that the sample in the peer and scientist condition actually comprised 119 students ($M_{\text{age}} = 14.74$, $SD = 1.00$, 49 female students, 64 male students, 5 diverse students). However, there was a significant difference between the conditions with regard to the used control variables (i.e., grade, self-concept, and interest in mathematics as well as the natural sciences). Therefore, in order to be able to include the variables, if appropriate, as covariates in our analyses (see, e.g., Miller and Chapman 2001), before conducting the analyses, we excluded four students from each condition based on their grades, self-concept, and interest in mathematics as well as the natural sciences. Thus, the groups no longer differed with regard to the control variables (see Appendix, Table 6).

data on beer foam decay in an OSL (see also Authors 2024a). Based on the steps of mathematical modelling with experiments (see Fig. 2), in both videos, the models first formulated different assumptions about how the beer foam decays (1. Assuming). Afterwards, they planned an experiment together to investigate beer foam decay and considered what materials they would need for it (2. Planning). They then carried out their planned experiment (3. Conduction), recording their measured values in a table (4. Mathematization) and subsequently transferring them to a coordinate system (5. Mathematical Work). Based on their graph, the models analyzed and interpreted the results (6. Interpretation) and compared them with their initial assumptions (7. Validation). Finally, they reflected together on their approach and thought about what they would do differently next time (8. Reflection).

Previously (i.e., at the beginning of the video), the three models in the video of the *peer condition* were introduced as peer students by showing photos of students of the same age. Whereas the three models in the video of the *scientist condition* were introduced as scientists by showing photos of adults who fulfilled stereotypical attributes of scientists from students' perspective, namely glasses, older age, more male than female, and a woman without styling (see, e.g., Authors 2021; Christidou 2011). In this way, we intended to ensure a high level of authenticity of the models and, thus, that students perceive them as real scientists. During the subsequent mathematical modelling with experimental data, in both videos only the models' arms and activities as well as written notes were visible (see Fig. 4) in order to draw students' attention to the aspects the models are talking about (see, e.g., van Gog and Rummel 2010). Students in both conditions heard the same voices but, to create a real conversation, with small differences in the language use.

Both videos could neither be stopped nor fasten-forwarded or rewound by the students. Moreover, there was an interruption of 45 s³ after each of the above steps in which the students had to answer multiple-choice questions related to the previously displayed content in order to motivate the students to actively watch the video, for instance: "Which assumptions are mentioned in the video?"

Fig. 4 Screenshot of the video (translated)



time in s	0	30	60	90	120	150	180	210	240
top edge in cm	3,6	3,2	2,8	2,6	2,3	2,2	2,1	2,0	2,0
bottom edge in cm	0,5	0,8	0,5	1,0	1,0	1,0	1,0	1,0	1,0
foam height in cm									

³ Please note that we shortened the interruptions in the videos in the present study compared to the previous one, as the participating students in the previous study only needed about half of the 90s to answer the questions. Therefore, although the videos are the same ones as in our previous study, they only last 25 min (instead of 30 min).

3.3.2 Lab booklets

In order to perform a mathematical modelling task with experimental data on the process of burning birthday candles themselves, students in both conditions were given a printed lab booklet which contained the assignments corresponding to the aforementioned eight steps of the people in the video (see also Fig. 2) and space for their notes.

3.4 Procedure

The study was conducted from August to December 2022 in an OSL and consisted of two learning phases (see Fig. 5). On the day of the intervention, we first explained the procedure of the study to the students in both conditions. Next, the students filled in a first questionnaire assessing their demographics as well as various control variables. Then we gave the students a short introduction to the importance of measurement data for successful experimentation. Afterwards, in the first learning phase, the students in both conditions watched the corresponding video modeling

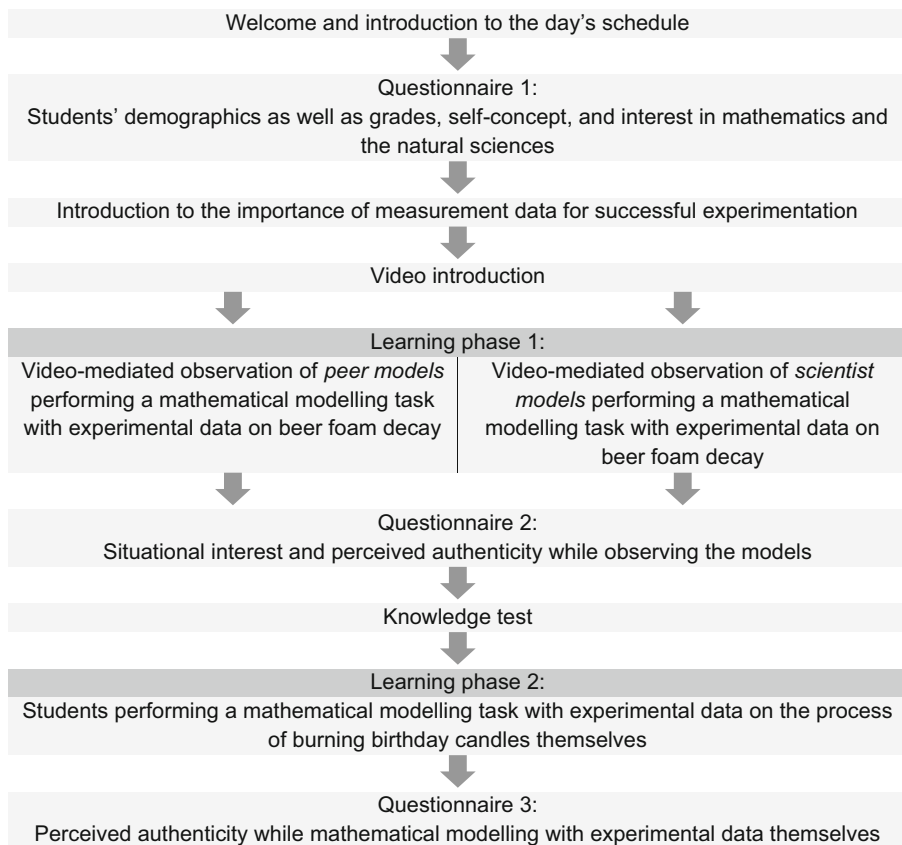


Fig. 5 Overview of the procedure

example on their own laptops using headphones. Immediately before watching the video, students received a short oral introduction to the technical features of the video (e.g., no possibility to stop, fasten-forward or rewind it). We also informed the students about the questions included in the video and a knowledge test that would follow. After the first learning phase (i.e., video-mediated observation), the students filled in a second questionnaire on their situational interest and their perceived authenticity while observing the models. After a break, the students worked on a knowledge test. We only administered the knowledge test after the intervention, as the participating students were not yet familiar with exponential processes before and, thus, the mathematical modelling task with experimental data on beer foam decay served as an exploration of exponential processes. The students had a total of 30 min to complete the knowledge test.

In the subsequent second learning phase, the students in both conditions formed small groups of three or in exceptional cases, due to class size constraints, of two or four. Then they had a total of 30 min to perform a similar mathematical modelling task with experimental data on the process of burning birthday candles themselves. After the second learning phase (i.e., students modelling with experimental data themselves), we administered a third questionnaire to assess students' perceived authenticity while mathematical modelling with experimental data themselves.

All questionnaires and the videos were provided in a computer-based learning environment.

3.5 Measures

A pre-questionnaire (administered prior to the first learning phase) assessed students' demographics (i.e., gender and age) as well as grades, self-concept, and interest in mathematics and the natural sciences as *control variables*. We assessed students' self-concept and interest in the mentioned subjects as control variables as it is hypothesized that these personal characteristics of learners may influence their perception of authenticity (Betz et al. 2016; see also Fig. 1). To measure students' self-concept, we used a questionnaire from PISA 2012 (Mang et al. 2018) which asked the students to rate five statements each per subject on a four-point Likert scale ranging from 1 (do not agree at all) to 4 (totally agree). Furthermore, we used a questionnaire from Rost et al. (2008) to assess students' interest in mathematics and the natural sciences by asking them to rate seven items each per subject on a six-point Likert scale ranging from 1 (does not apply at all) to 6 (totally applies).

To measure students' *perceived authenticity*, we used a questionnaire (FEWAW) from Finger et al. (2022) which distinguishes between the following four dimensions of perceived authenticity in science education: instructor, location, method, and innovation. After the first learning phase, we used a slightly adapted version to measure students' perceived authenticity of the observed models, the location where the observed models performed the mathematical modelling task with experimental data, the methods the observed models used, and the innovation of the mathematical

Table 1 Example items and internal consistencies of the questionnaire scales

Scale (number of items)	Adapted from ...	Example item	Cronbach's α
Subject-related self-concept (5 items)	Mang et al. (2018)	In mathematics/biology/chemistry/physics/the natural sciences, I learn quickly	>0.67
Subject-related interest (7 items)	Rost et al. (2008)	I enjoy working on tasks in mathematics/biology/chemistry/physics/the natural sciences	>0.90
Perceived authenticity of ...	Finger et al. (2022)		
... the observed models/the instructor (3 items)		The observed people in the video/My instructors are real scientists	0.68/0.67
... the location where the observed models performed the mathematical modelling task with experimental data/the location (3 items)		The observed people in the video/I worked at a location where research takes place	0.83/0.81
... the method the observed models used/the method (4 items)		The observed people in the video/I used scientific methods	0.71/0.76
... the innovation of the mathematical modelling process performed by the observed models/the innovation (3 items)		The observed people in the video/I worked on a research question to which research has not yet an answer	0.63/0.75
Situational interest	Lewalter and Geyer (2009)		
Catch (6 items)		Did the beer foam experiment capture your attention?	0.93
Hold (6 items)		Did any new questions arise for you during the beer foam experiment that you would like to have an answer to?	0.85

modelling process performed by the observed models.⁴ After the second learning phase, we administered the original version of the questionnaire and, thus, assessed students' perceived authenticity of the instructor, location, method, and innovation. In both versions, students were asked to rate 13 different statements on a five-point Likert scale ranging from 1 (completely wrong) to 5 (completely right).

To measure students' *situational interest*, we used a questionnaire from Lewalter and Geyer (2009). We slightly adapted the wording of the items for the learning environment of the present study. According to Hidi and Renninger (2006), students were asked to rate six items on their triggered (i.e., catch dimension) and six items on their maintained (i.e., hold dimension) situational interest on a five-point Likert scale ranging from 1 (not at all) to 5 (a lot). Example items and the internal consistencies of all scales are depicted in Table 1. The internal consistencies are at least nearly

⁴ In addition, we also assessed students' perceived authenticity of their own method (i.e., the video mediated observation of peer or scientist models) with the corresponding items of the original questionnaire from Finger et al. (2022). However, for testing the hypotheses of the present paper, only students' perceived authenticity related to the video-mediated observation is of interest.

acceptable, most are more than acceptable as Cronbach's alphas are higher than 0.70 (see, e.g., Cicchetti and Sparrow 1990).

To assess students' *knowledge acquisition*, we used 25 items in a self-developed knowledge test that tested students' knowledge about exponential decay (i.e., reproduction task on the decay of milk foam) and growth (i.e., transfer task on the growth of cress) processes (see also Authors 2024a). The items asked the students to reproduce or transfer the knowledge they gained while observing the video modeling example, especially in terms of interpreting and validating, as previous studies found this to be particularly challenging for students when modelling in general (e.g., Blum and Borromeo Ferri 2009; Blum and Leiß 2007) and modelling with experimental data in particular (e.g., Geisler 2021b). For the most part, the students were asked to first select which answers they thought were correct from given statements (i.e., closed-ended items) and then to explain their choice (i.e., open-ended items). Afterwards, the students were shown various explanations and they were asked to choose the correct ones (i.e., closed-ended items). For example, the students were shown a graph and five statements describing the decay of milk foam, such as "At the beginning, the milk foam decays quickly and then increasingly slower over time." or "The milk foam always decays at the same speed." The students were asked to first select the correct statements and then to explain their choice. After completing the task, the students were shown ten possible explanations for the aforementioned statements describing the decay of milk foam and they were asked to choose the correct ones. The students could achieve a total of 55.5 points. Two raters coded around 20% of the knowledge test of the larger study from which the present data originate with satisfactory interrater reliability (ICC=0.95; 95%-CI [0.95, 0.96]). As the results of a principal axis factor analysis with oblique rotation (direct oblimin) suggested one factor that unified all items, we considered students' overall knowledge acquisition. The internal consistency of the 25 items is good (Cronbach's $\alpha=0.80$).

4 Results

4.1 Research objective 1

4.1.1 Students' perceived authenticity of the observed models

To test whether students who observe scientist models report higher perceived authenticity of the observed models than students who observe peer models (H1), we conducted a MANCOVA with condition as factor and students' perceived authenticity as dependent variable. We included students' interest in mathematics as well as the natural sciences as covariates due to significant correlations with students' perceived authenticity of the observed method (see Appendix, Table 7). In line with our H1, the analysis reveals a significant effect of condition on students' perceived authenticity, $F(4, 104)=3.71$, $p=0.004$ (one-sided), $\eta_p^2=0.13$. We conducted post-hoc univariate ANCOVAs for every adapted authenticity dimension (i.e., perceived authenticity of the observed models, the location where the observed models performed

Table 2 Descriptive statistics for students' perceived authenticity after the first learning phase (i.e., video-mediated observation)

Perceived authenticity of ...	Peer condition <i>n</i> = 58 <i>M</i> (<i>SD</i>)	Scientist condition <i>n</i> = 53 <i>M</i> (<i>SD</i>)
... the observed models	2.99 (0.86)	3.38 (0.92)
... the location where the observed models performed the mathematical modelling task with experimental data	3.74 (0.97)	3.66 (0.99)
... the method the observed models used	3.71 (0.75)	3.70 (0.83)
... the innovation of the mathematical modelling process performed by the observed models	2.75 (1.05)	2.62 (0.90)

the mathematical modelling task with experimental data, the method the observed models used, and the innovation of the mathematical modelling process performed by the observed models). As expected, the analyses show a significant difference between students' perceived authenticity of the observed models, $F(1, 107) = 5.49$, $p = 0.006$ (one-sided), $\eta_p^2 = 0.05$, and no significant differences between students' perceived authenticity in any of the other adapted authenticity dimensions (the location where the observed models performed the mathematical modelling task with experimental data: $F(1, 107) = 0.27$, $p = 0.605$ (two-sided), $\eta_p^2 < 0.01$; method the observed models used: $F(1, 107) = 0.08$, $p = 0.782$ (two-sided), $\eta_p^2 < 0.01$; innovation of the mathematical modelling process performed by the observed models: $F(1, 107) = 1.35$, $p = 0.247$ (two-sided), $\eta_p^2 = 0.01$). Table 2 provides the descriptive statistics with regard to students' perceived authenticity.

4.1.2 Students' situational interest

To test whether students who observe scientist models report higher situational interest than students who observe peer models (H2) and whether the effect of observing models with a different degree of authenticity on students' situational interest is mediated by their perceived authenticity of the observed models (H3), we conducted two mediation analyses. We used condition as a predictor variable (X) and students' situational interest (either catch or hold) as an outcome variable (Y). We only considered students' perceived authenticity of the observed models as a mediator (M) variable in our mediation analyses, as we only found, as expected, differences between the two groups in this adapted authenticity dimension. We included students' self-concept in the natural sciences and interest in mathematics as well as the natural sciences as covariates due to significant correlations with students' triggered and maintained situational interest (see Appendix, Table 7). We conducted the mediation analyses with 95% percentile bootstrap confidence intervals from 10,000 bootstrap samples using the SPSS macro PROCESS (see Hayes 2022). Contrary to our H2, the analyses reveal a significant negative effect of condition on both students' triggered (see Fig. 6) and maintained (see Fig. 7) situational interest. In other words, students who observed peer models reported significant higher triggered and maintained situational interest than students who observed scientist models. As already mentioned with regard to students' perceived authenticity, the analyses indicate a significant

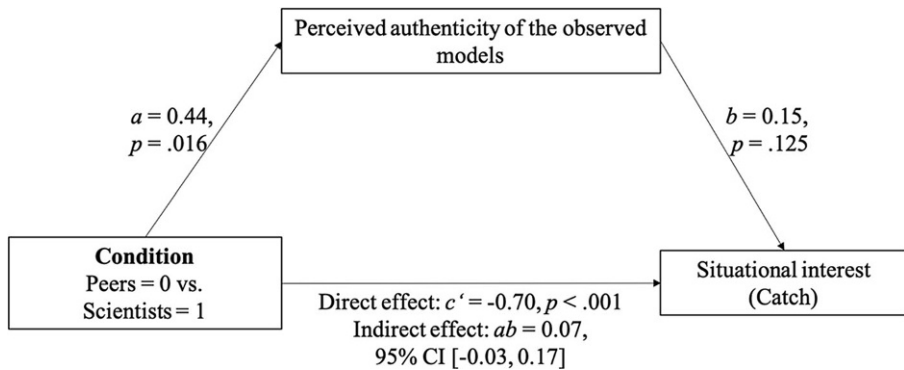


Fig. 6 Results of the mediation analysis with triggered situational interest as outcome variable

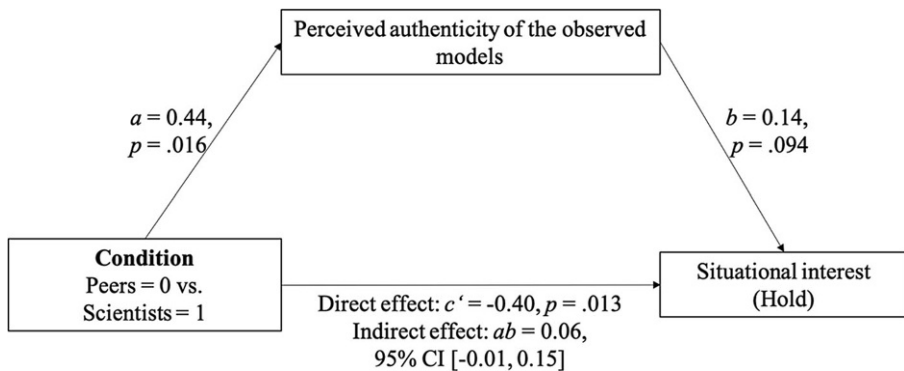


Fig. 7 Results of the mediation analysis with maintained situational interest as outcome variable

effect of the condition on students' perceived authenticity of the observed models, which, in turn, did not significantly affect students' triggered or maintained situational interest. Furthermore, against our H3, the analyses reveal neither a significant indirect effect of condition on students' triggered nor maintained situational interest through their perceived authenticity of the observed models (which is indicated by the fact that zero is included in the bootstrap confidence intervals; e.g., Field 2018). The descriptive statistics regarding students' situational interest are shown in Table 3.

4.1.3 Students' knowledge acquisition

To test the contradictory hypotheses that, one the one hand, students who observe peer models achieve higher performance on a knowledge test than students who observe scientist models (H4a) or, on the other hand, students who observe scientist models achieve higher performance on a knowledge test than students who observe peer models (H4b) and whether the effect of observing models with a different degree of authenticity on students' knowledge acquisition is mediated by their perceived authenticity of the observed models (H5), we again conducted a mediation

Table 3 Descriptive statistics for students' situational interest

	Peer condition <i>n</i> = 58 <i>M</i> (<i>SD</i>)	Scientist condition <i>n</i> = 53 <i>M</i> (<i>SD</i>)
Situational interest (catch)	2.74 (1.09)	2.23 (0.90)
Situational interest (hold)	2.13 (0.92)	1.91 (0.82)

analysis. We used condition as a predictor variable (X), students' knowledge test performance as an outcome variable (Y), and students' perceived authenticity of the observed models as a mediator (M) variable. Due to significant correlations with students' knowledge test performance, we included students' grades in mathematics and the natural sciences, self-concept in mathematics and the natural science, as well as interest in mathematics and the natural science as covariates (see Appendix, Table 7). Again, we conducted the mediation analysis with 95% percentile bootstrap confidence intervals from 10,000 bootstrap samples using the SPSS macro PROCESS (see Hayes 2022). Neither in line with our H4a nor H4b, the analysis indicates a significant direct effect of condition on students' knowledge test performance (see Fig. 8). Moreover, against our H5, the analysis reveals neither a significant effect of students' perceived authenticity of the observed models on their knowledge test performance nor a significant indirect effect of the intended model authenticity on students' knowledge test performance through perceived authenticity of the observed models. Table 4 provides the descriptive statistics with regard to students' knowledge test performance.

4.2 Research objective 2

To explore to what extent observing either peer or scientist models affects students' perception of authenticity when subsequently performing a similar mathematical modelling task with experimental data themselves (RO2), we conducted a mixed MANCOVA with condition as between-subject factor, learning phase as within-subject factor and students' perceived authenticity as dependent variable. We included students' grade in mathematics and interest in mathematics as well as the natural

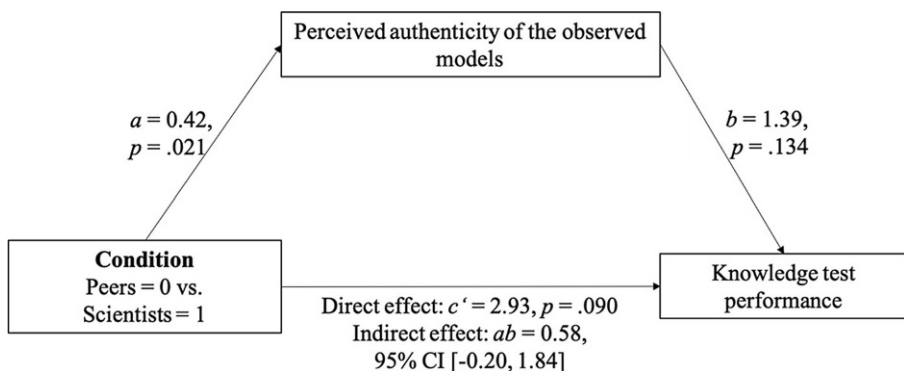
**Fig. 8** Results of the mediation analysis with knowledge test performance as outcome variable

Table 4 Descriptive statistics for students' knowledge test performance

	Peer condition <i>n</i> = 58 <i>M</i> (<i>SD</i>)	Scientist condition <i>n</i> = 53 <i>M</i> (<i>SD</i>)
Knowledge test performance	19.59 (8.39)	21.64 (10.28)

sciences as covariates due to significant correlations with students' perceived authenticity of the observed method after the first learning phase and students' perceived authenticity of the instructor, location, method, and innovation after the second learning phase (see Appendix, Table 7). The analysis reveals a significant triple interaction between condition, learning phase, and students' perceived authenticity, Huynh-Feldt $F(3, 252) = 7.82$, $p < 0.001$ (two-sided), $\eta_p^2 = 0.09$. The descriptive statistics are depicted in Table 5.

With regard to *intergroup differences in learning phase 2* (i.e., differences in students' perception of authenticity during modelling with experimental data themselves between students in both conditions), pairwise comparisons (see Appendix, Table 8) did not reveal significant intergroup differences.

With respect to *intrasubject differences* (i.e., differences in students' perception of authenticity between learning phase 1 and 2), pairwise comparisons (see Appendix, Table 9) show differences for both conditions with regard to students' perceived authenticity of the instructor and the location. While students in the peer condition perceived the instructors in the second learning phase, namely the early career scientists who guided the day-long lab project in the OSL, as significant more authentic than the previously observed peer models in the first learning phase, $M_{\text{Diff}} = 0.47$, Bonferroni-corrected $p = 0.027$, 95% CI [0.05, 0.88], students in the scientist condition perceived them as significant less authentic than the previously observed scientist models, $M_{\text{Diff}} = -0.56$, Bonferroni-corrected $p = 0.002$, 95% CI [-0.89, -0.22]. Furthermore, regarding students' perception of authenticity of the location, the results reveal that students in both conditions perceived the location, namely the OSL, significant more authentic when modelling with experimental data there themselves (i.e., in learning phase 2) than when observing others performing a mathematical modelling task with experimental data there in a video recording (i.e., learning phase 1), $M_{\text{Diff}} = 0.61$, Bonferroni-corrected $p < 0.001$, 95% CI [0.27, 0.95] (peer condition) and $M_{\text{Diff}} = 0.32$, Bonferroni-corrected $p = 0.023$, 95% CI [0.05, 0.60] (scien-

Table 5 Descriptive statistics for students' perceived authenticity after the second learning phase (i.e., students modelling with experimental data themselves)

Perceived authenticity of ...	Peer condition <i>n</i> = 36 ^a <i>M</i> (<i>SD</i>)	Scientist condition <i>n</i> = 53 <i>M</i> (<i>SD</i>)
... the instructor	3.27 (1.17)	2.82 (0.92)
... the location	4.33 (0.84)	3.99 (0.79)
... the method	3.91 (0.95)	3.90 (0.69)
... the innovation	2.92 (1.40)	2.77 (0.96)

^aPlease note that due to technical problems in filling in the questionnaire on students' perceived authenticity while modelling with experimental data themselves (i.e., after learning phase 2), data are not available for all students in the peer condition, but only for 36 of the 58 students

tist condition). With regard to students' perception of authenticity of the method and the innovation, the results further show no significant differences between learning phase 1 and 2 for students in both conditions.

5 Discussion and outlook

Out-of-school labs (OSLs) are considered a promising opportunity to provide students with authentic experiences as they, for instance, often engage students in authentic activities that emulate the work of professionals of a certain discipline (see, e.g., Garner and Eilks 2015; Nachtigall and Rummel 2021; Scharfenberg and Bogner 2014). One key component of the work of professionals in many empirical scientific disciplines, such as the natural sciences, is mathematical modelling (see, e.g. Niss 1994). Especially through the combination of modelling with hands-on experiments (e.g., Geisler 2021a, b; Geisler and Rach 2023; Halverscheid 2008; Zell and Beckmann 2009) and, thus, the use of real data, which usually do not perfectly fit a mathematical model and make validation necessary (see, e.g., Engel 2010; Geisler 2021a, b), the work of professionals of many scientific disciplines can be simulated for students. However, such authentic learning activities may cognitively overwhelm learners (e.g., Nachtigall et al. 2024) and previous research in OSLs (e.g., Hohrath et al. 2024; Nachtigall and Rummel 2021; Nachtigall et al. 2018) further shows that they are often not perceived as authentic as intended by students due to different perceptions about authentic (i.e., professionally contextualized) practices between those who develop learning settings and the participants as well as students' lack of prior knowledge and experience. As a result, the hypothesized positive motivational and cognitive effects of authentic learning (see, e.g., Betz et al. 2016) are often not evoked. This is likely to be the case especially for mathematical modelling with experimental data, as mathematical modelling with experimental data is rarely implemented in mathematics classes (e.g., Halverscheid 2008) and, thus, students have no or only few experience and many difficulties (e.g., Geisler 2021b; see also, e.g., Blum and Borromeo Ferri 2009; Blum and Leiß 2007). Therefore, based on the example-based-learning-principle (e.g., van Gog and Rummel 2010; van Harsel et al. 2022) as well as empirical evidence that the implementation of videos of working scientists can foster students' perception of authenticity and convey an authentic conception of scientists' work in an OSL (e.g., Stamer et al. 2021), the present paper focused on providing students with first authentic and not too cognitively demanding insights into mathematical modelling with experimental data by letting them observe corresponding video modeling examples followed by modelling with experimental data themselves in an OSL.

Against this background, in a previous study (Authors 2024a), we have begun to investigate the effects of observing models with a different degree of authenticity (i.e., peer models vs. scientist models) of mathematical modelling with experimental data on students' perceived authenticity as well as their motivational (i.e., situational interest) and cognitive (i.e., knowledge acquisition) learning outcomes. The aim of the present study was to, on the one hand, conceptually replicate (e.g., Schmidt 2009) our previous study, which took place at the students' school, in an OSL and,

on the other hand, extend it by having the students performing a similar mathematical modelling task with experimental data themselves after observing the video modeling examples. Specifically, the present study aimed to investigate the effects of observing either peer or scientist models of mathematical modelling with experimental data in an OSL on students' perceived authenticity, their situational interest, and their knowledge acquisition (RO1) as well as their perception of authenticity during subsequently performing a similar mathematical modelling task with experimental data themselves (RO2).

As expected (H1) and also found in our previous school study (see Appendix, Table 10), our results show that students who observed scientist models reported significantly higher perceived authenticity of the observed models than students who observed peer models. This finding may not seem surprising, as we used people with stereotypical attributes of scientists (see, e.g., Authors 2021; Christidou 2011) as scientist models, but nevertheless again supports the assumption that the (virtual) presence of experts can be a design element for creating authentic learning settings (e.g., Nachtigall et al. 2022). However, at the same time, our findings regarding RO2 reveal that the observation of such stereotypical scientists leads to perceiving non-stereotypical scientists, like the early career scientists who guided the day-long OSL project, as less authentic. Even though we decided to use pictures of stereotypical scientists to ensure that students actually perceive them as scientists, it would be worthwhile to also use non-stereotypical scientist models and investigate the effects on students' perceived authenticity as well as further learning outcomes in future studies. Furthermore, when comparing the descriptive statistics of both studies regarding students' overall perceived authenticity (see Appendix, Table 11), it is noticeable that the students, although they watched the same videos, perceived slightly less authenticity in almost all of the four adapted authenticity dimensions in the OSL in the present study. Only students' perceived authenticity of the method the observed models used is quite similar in both studies and both conditions. One possible reason for this could be that the students of the present study watched the video already in a learning location that they may have perceived as authentic. This could have meant that they no longer perceived the authentic video setting as being as authentic as they would have if they had viewed the video at their own school as a less authentic learning location. Thus, our results suggest that watching an authentic video setting may lose its impact on students' perception of authenticity if it is viewed in an already authentic location, such as an OSL. Our results regarding RO2 support this assumption, as they reveal that students in both conditions perceived the same location, namely the OSL, as significantly more authentic when modelling with experimental data there themselves (i.e., in learning phase 2) than when observing others performing a mathematical modelling task with experimental data there in a video recording.

This could also be a possible reason for the unexpected results with regard to the hypothesized motivational effects of authentic learning. Contrary to our expectation (H2) and different from our previous study, students who observed peer models reported significant higher triggered and maintained situational interest than students who observed scientist models. Furthermore, as in our previous study, we found no indirect effect on either students' triggered or maintained situational interest

mediated by their perceived authenticity of the observed models (against H3). Our findings, therefore, indicate once again that the expected effects of authentically designed learning settings on students' motivational learning outcomes (e.g., Betz et al. 2016), such as students' situational interest, may be overrated (see also, e.g., Nachtigall and Rummel 2021). It seems that features other than students' perceived authenticity of the observed models play a more important role in the development of students' situational interest in the OSL. One possible reason why students find the observation of peer models more interesting than the observation of scientist models could relate to the model-observer similarity hypothesis (e.g., Schunk 1987). Observing models similar in age and expertise as well as being in the same location as shown in the video and the fact that other students were also experimenting in the other rooms of the OSL may have led the students to be able to identify themselves more with the peer models in the video. This may have resulted in the students finding the observation of peer models more interesting and tending to perceive (descriptively) more authenticity in the different dimensions.

With regard to the expected positive cognitive effects of authentic learning, we, again, found neither a significant effect of condition on students' knowledge acquisition (against both H4a and H4b) nor an indirect effect mediated by students' perceived authenticity of the observed models (against H5). As in our previous study, students in both conditions performed poorly on the knowledge test. One possible reason for this could be that the knowledge test was administered shortly after the first exploration of exponential processes (by observing the video modeling examples) for the students who probably have no or only few experience with mathematical modelling (with experimental data) and, thus, validating, in particular. In combination with the fact that students were previously only familiar with linear processes and the presumably unfamiliar format of the test with the closed-ended and open-ended reasoning items, this possibly has overstrained the students. Therefore, in future studies, it would be worthwhile to not only consider students' performance in a written knowledge test, but also to examine further learning outcomes. For example, students' process-related skill acquisition may be assessed by videotaping the students while performing the mathematical modelling task with experimental data themselves in the second learning phase and then analyzing the videos with regard to students' skills in mathematical modelling with experimental data. In addition, due to the fact that we only used the knowledge test after the intervention because students were not yet familiar with exponential processes before participating in our study, we are not able to give any information about the extent to which their knowledge increased. To address this limitation, future studies should also assess students' prior knowledge. In addition, although previous research suggests that students likely have no or only few experience with mathematical modelling in general and mathematical modelling with experimental data in particular (e.g., Halverscheid 2008; Jordan et al. 2008), it would also be useful to survey their prior experience as another control variable. This would also address another limitation of the present study, namely the quasi-experimental design which we implemented due to the fact that the larger study from which we used data in the present paper took place in an OSL that is usually visited by whole classes. Furthermore, this would also contribute to being able to compare the groups with regard to further control variables which

potentially influenced the results. Although the results of the MANOVA did not reveal a significant difference between the reduced sample in the peer and scientist condition with regard to the used control variables (i.e., grades, self-concept, and interest in mathematics as well as the natural sciences; see Appendix, Table 6), this does not necessarily mean that the groups do not differ.

By extending our previous research through the implementation of the second learning phase (i.e., students modelling with experimental data themselves after observing video modeling examples) in the present study, we are now able to draw conclusions about the extent to which observing models with a different degree of authenticity affects students' perception of authenticity when subsequently performing a similar mathematical modelling task with experimental data themselves (RO 2). Our results reveal no significant difference in students' perception of authenticity during performing a mathematical modelling task with experimental data themselves after observing either peer or scientist models of mathematical modelling with experimental data. Thus, our results do not support the findings by Stamer et al. (2021) indicating that the implementation of videos of working scientists can foster students' perception of authenticity and convey an authentic conception of scientists' work in an OSL. One may assume that this could be due to the fact that the participants in the study by Stamer et al. (2021) observed scientists during working on relevant and up to date scientific topics, whereas the models of the present study (i.e., also the scientist models) worked on a task which is considered more typical for students rather than for "real" scientists. However, as the descriptive statistics (see Table 2) show, students perceived mathematical modelling with experimental data already as an authentic method after the first learning phase (i.e., video-mediated observation), regardless of whether peer or scientist models were observed. Thus, with regard to the perception of authenticity, it does not seem necessary to ask students to first observe video modeling examples of mathematical modelling with experimental data before subsequently modelling with experimental data themselves in an OSL. However, if the resources for students modelling with experimental data themselves are not available, for example, at school, the use of corresponding video modeling examples represents a suitable alternative for providing students with authentic experiences. Even though it may take a lot of effort to create such video modeling examples, it still seems worthwhile, as they can be used multiple times and in many different ways. For instance, the video modeling examples may be made available digitally so that students can watch them outside of the regular mathematics lessons. This would also counteract the argument of mathematics teachers that mathematical modelling with experimental data is often not implemented in mathematics lessons due to lack of time (see, e.g., Authors 2024b; Halverscheid 2008).

In summary, the results of the present study mostly replicate the findings of our previous school study (see Authors 2024a). Again, students perceived the scientist models as more authentic than the peer models. Furthermore, we again found neither a direct effect of condition nor an indirect effect mediated by students' perceived authenticity of the observed models on students' situational interest and knowledge acquisition. Thus, the results of the present study support our assumption that students' perception of authenticity seems to play a less important role than hypothesized and than other variables (e.g., a possibly greater identification with the peer

models in the video due to other students also experimenting in the OSL) in fostering their motivational (and cognitive) learning outcomes. Furthermore, the results of the present study indicate that observing either peer or stereotypical scientist models of mathematical modelling with experimental data did not affect students' perception of authenticity of the method when subsequently performing a similar mathematical modelling task with experimental data themselves, but their perceived authenticity of the early career scientists who guided the day-long lab project in the OSL who did not fulfill the stereotypical image of scientists.

6 Appendix

Table 6 Descriptive statistics of the control variables (i.e., students' grades, self-concept, and interest in mathematics as well as the natural sciences) and results of the MANOVA

	Peer condition <i>n</i> = 58 <i>M</i> (<i>SD</i>)	Scientist condition <i>n</i> = 53 <i>M</i> (<i>SD</i>)	<i>F</i> (1, 109)	<i>p</i>	η^2_p
Grade in mathematics	2.50 (1.14)	2.77 (1.22)	1.49	0.225	0.01
Grade in the natural sciences	2.27 (0.67)	2.23 (0.75)	0.08	0.781	<0.01
Self-concept in mathematics	2.72 (0.88)	2.58 (0.81)	0.79	0.375	0.01
Self-concept in the natural sciences	2.70 (0.59)	2.91 (0.51)	3.88	0.052	0.03
Interest in mathematics	3.12 (1.64)	2.83 (1.57)	0.91	0.343	0.01
Interest in the natural sciences	3.02 (1.40)	3.33 (0.97)	1.70	0.195	0.02

Table 7 Significant correlations between the control variables and the dependent variables

	Grade in mathematics	Grade in the natural sciences	Self-concept in mathematics	Self-concept in the natural sciences	Interest in mathematics	Interest in the natural sciences
Perceived authenticity of ...						
... the method the observed models used				–	$r = 0.21, p = 0.030$	$r = 0.24, p = 0.011$
Situational interest (catch)				$r = 0.19, p = 0.048$	$r = 0.24, p = 0.013$	$r = 0.37, p < 0.001$
Situational interest (hold)				$r = 0.22, p = 0.019$	$r = 0.21, p = 0.025$	$r = 0.40, p < 0.001$
Knowledge test performance	$r = -0.44, p < 0.001$	$r = -0.31, p = 0.001$	$r = 0.39, p < 0.001$	$r = 0.25, p = 0.008$	$r = 0.34, p < 0.001$	$r = 0.20, p = 0.032$
Perceived authenticity of ...						
... the instructor					$r = 0.24, p = 0.024$	
... the location	$r = -0.21, p = 0.049$				$r = 0.27, p = 0.012$	$r = 0.26, p = 0.015$
... the method						$r = 0.30, p = 0.004$
... the innovation						$r = 0.22, p = 0.041$

Table 8 Differences in students' perception of authenticity in learning phase 1 and 2 between the conditions (i.e., intergroup differences)

	Authenticity dimension	M_{Diff} (between peers and scientists condition)	Bonferroni-corrected p	95% CI
Learning phase 1 (i.e., video-mediated observation)	Instructor	-0.60	0.003	[-0.99, -0.21]
	Location	0.03	0.893	[-0.43, 0.49]
	Method	0.11	0.528	[-0.24, 0.47]
	Innovation	0.23	0.301	[-0.21, 0.67]
Learning phase 2 (i.e., students modelling with experimental data themselves)	Instructor	0.42	0.066	[-0.03, 0.87]
	Location	0.32	0.079	[-0.04, 0.67]
	Method	0.01	0.956	[-0.34, 0.36]
	Innovation	0.26	0.302	[-0.24, 0.75]

Table 9 Differences in the perception of authenticity by students in both conditions between learning phase 1 and 2 (i.e., intragroup differences)

	Authenticity dimension	M_{Diff} (between learning phase 1 and 2)	Bonferroni-corrected p	95% CI
Peer condition	Instructor	-0.47	0.027	[-0.88, -0.05]
	Location	-0.61	<0.001	[-0.95, -0.27]
	Method	-0.09	0.558	[-0.39, 0.21]
	Innovation	-0.19	0.289	[-0.53, 0.16]
Scientist condition	Instructor	0.56	0.002	[0.22, 0.89]
	Location	-0.32	0.023	[-0.60, -0.05]
	Method	-0.19	0.123	[-0.44, 0.05]
	Innovation	-0.16	0.277	[-0.44, 0.13]

Table 10 Comparison of the results of our previous and present study (differences highlighted in bold)

Hypotheses	Previous study ($n = 105$) (Authors 2024a)	Present study ($n = 111$)
Effect of model authenticity (peers vs. scientists) on students' perceived authenticity	$F(4, 99) = 2.62, p = 0.020$ (one-sided), $\eta_p^2 = 0.10$	$F(4, 104) = 3.71, p = 0.004$ (one-sided), $\eta_p^2 = 0.13$
Effect of model authenticity (peers vs. scientists) on students' perceived authenticity of the observed models	$F(1, 102) = 4.19, p = 0.022$ (one-sided), $\eta_p^2 = 0.04$	$F(1, 107) = 5.49, p = 0.006$ (one-sided), $\eta_p^2 = 0.05$
Effect of model authenticity (peers vs. scientists) on students' situational interest (catch)	Direct effect: $c' = 0.06, p = 0.730$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = 0.09, 95\% \text{ CI } [-0.01, 0.24]$	Direct effect: $c' = -0.70, p < 0.001$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = 0.07, 95\% \text{ CI } [-0.03, 0.17]$
Effect of model authenticity (peers vs. scientists) on students' situational interest (hold)	Direct effect: $c' = -0.08, p = 0.639$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = 0.09, 95\% \text{ CI } [-0.03, 0.15]$	Direct effect: $c' = -0.40, p = 0.013$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = 0.06, 95\% \text{ CI } [-0.01, 0.15]$
Effect of model authenticity (peers vs. scientists) on students' knowledge test performance	Direct effect: $c' = 0.60, p = 0.677$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = -0.18, 95\% \text{ CI } [-0.96, 0.34]$	Direct effect: $c' = 2.93, p = 0.090$ Indirect effect (mediated by students' perceived authenticity of the observed models): $ab = 0.58, 95\% \text{ CI } [-0.20, 1.84]$

Table 11 Comparison of the descriptive statistics regarding students' overall perceived authenticity of our previous and present study

Perceived authenticity of ...	Previous study (Authors 2024a)		Present study			
			Learning phase 1		Learning phase 2	
	Peer condition ($n = 52$)	Scientist condition ($n = 53$)	Peer condition ($n = 58$)	Scientist condition ($n = 53$)	Peer condition ($n = 36$)	Scientist condition ($n = 53$)
... the observed models/the instructor	3.11 (0.92)	3.55 (0.99)	2.99 (0.86)	3.38 (0.92)	3.27 (1.17)	2.82 (0.92)
... the location (where the observed models performed the mathematical modelling task with experimental data)	3.97 (0.77)	3.92 (0.76)	3.74 (0.97)	3.66 (0.99)	4.33 (0.84)	3.99 (0.79)
... the method (the observed models used)	3.75 (0.70)	3.70 (0.81)	3.71 (0.75)	3.70 (0.83)	3.91 (0.95)	3.90 (0.69)
... the innovation (of the mathematical modelling process performed by the observed models)	2.95 (0.91)	2.89 (1.07)	2.75 (1.05)	2.62 (0.90)	2.92 (1.40)	2.77 (0.96)

Acknowledgements The content of this manuscript has been partly published as part of the dissertation thesis of the first author (Hagenkötter 2023). This research was funded within the doctoral program “Metacognitive Monitoring in Authentic Teaching and Learning Contexts in Out-of-School Labs” (MeMo-akS) by the Professional School of Education (PSE) of the Ruhr-University Bochum. We would like to thank all members of the program for their feedback on the design of this study, the team of the Alfred Krupp-Schülerlabor der Wissenschaften (out-of-school lab) for their cooperation as well as the school classes who participated in this study.

Funding Open Access funding enabled and organized by Projekt DEAL.

Conflict of interest R. Hagenkötter, V. Nachtigall, K. Rolka and N. Rummel declare that they have no competing interests.

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