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Constructing Graphs in Biology Class: Secondary Biology Teachers' Beliefs, Motivation, and Self-Reported Practices

Carolin Enzingmüller[1] · **Helmut Prechtl**[2]

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Abstract

There has been a growing awareness that graphing is an essential part of the science curriculum. While much research has focused on student conceptions and abilities regarding graphical representations, only few studies have investigated what teachers think about them and how they use graphs in science class. The purpose of this study is to explore educational beliefs, motivation, and teaching practices of German secondary biology teachers regarding graph construction. Via questionnaire surveys, 71 teachers from different regions in Germany rated their beliefs and motivation as well as the frequency of different graph construction activities in biology class. The teachers surveyed in this study were quite motivated in their teaching of graph construction. Furthermore, they tended to believe that graph construction should be practiced explicitly in biology class and that students should learn clear strategies for constructing graphs. We found that teaching subjects and own research experience make a difference in teachers' beliefs and motivation regarding graph construction in biology class. The self-report on classroom practices revealed that participants may provide limited opportunities for students to experience graphing as a social and iterative practice. Implications are drawn for teacher education and professional development as well as for further research in teacher education contexts.

Keywords Biology teachers · Beliefs and motivation · Classroom practices · Graph construction · Secondary school

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✉ Carolin Enzingmüller
enzingmueller@ipn.uni-kiel.de

[1] IPN - Leibniz Institute for Science and Mathematics Education, Kiel, Germany

[2] University of Potsdam, Potsdam, Germany

Scientists rely on a variety of representations to construct and communicate their knowledge (Lemke, 1998). Among others, graphs, charts, diagrams, and tables are used to illustrate phenomena and to organize and convey information. These displays generated as a result of scientific activities have been referred to as inscriptions (Latour, 1987; Roth & McGinn, 1998). In contrast to representations that can be mental in nature, inscriptions are "signs that are embodied in some medium, such as paper or computer monitors" (Roth & McGinn, 1998, p. 37). Research revealed that these external representations are central to the practice of science (Kozma, 2003; Kozma, Chin, Russell, & Marx, 2000; Kozma & Russell, 1997). Graphs in particular are "especially useful for presenting complex sets of information within a single inscription" (Pozzer-Ardenghi & Roth, 2010, p. 245). Hence, graphs are often used to present scientific research results and very common in scientific journal articles (Roth, Bowen, & McGinn, 1999). In the process of scientific inquiry, they serve as reasoning tools for generating hypotheses, elaborating ideas, justifying arguments, and making conclusions (Kozma et al., 2000). In addition, graphs are used to convey scientific concepts in school science textbooks, newspapers, and magazines (Zacks, Levy, Tversky, & Schiano, 2002). In accordance with the essential role of graphs in inquiry processes and in communicating science, there is a growing awareness that interpreting and constructing graphs, along with tables, diagrams, and other representations, are important learning practices for the development of scientific literacy (Norris & Phillips, 2003; Tang & Moje, 2010; Yore, Pimm, & Tuan, 2007). Thus, representational practices are included in various standards and curricula. The German National Educational Standards for biology, for example, recommend that by the end of 10th grade, students should be able to extract and process information from graphs and other graphical representations, make connections between them, create graphs to visualize data, and comment on representational practices (Kultusministerkonferenz [KMK], 2005).

Although teachers are expected to address these practices in their instruction, some researchers argue that teachers might not be able to employ graphical representations to their fullest potential (Bowen & Roth, 2005; Coleman, McTigue, & Smolkin, 2011; Eilam, Poyas, & Hashimshoni, 2014; McElvany et al., 2012; Morrison & McDuffie, 2009; Nitz, Ainsworth, Nerdel, & Prechtl, 2014; Patahuddin & Lowrie, 2019). For example, Eilam (2012) and Eilam et al. (2014) identified deficient competencies to interpret or to create graphical representations among preservice and in-service teachers alike. Besides the required knowledge and skills, they also pointed out the importance of teachers' perceptions and awareness as prerequisites for successful instruction regarding graphical representations.

Graphs are considered not only quintessential representations in science (Pozzer-Ardenghi & Roth, 2010) but also key features in science learning (Boote, 2014; Wang et al., 2012). This study therefore investigated biology teachers' beliefs and motivation directly related to graph construction as one area of graphing and explored possible connections to teachers' practices regarding graph construction.

Theoretical Background

Learning from and with Graphs in Science Class

Graphs are visual displays that convey information via different types of spatial relations (Kosslyn, 1989). We focused on line and bar graphs, which are widely used by scientists when organizing and displaying scientific data (Zacks et al., 2002). Since line and bar graphs both illustrate the relationship among variables with at least one continuous variable, they share similar structural components. Both have an L-shaped framework, and each leg of the framework is specified with a label describing what is being measured and which unit is used (Friel, Curcio, & Bright, 2001). The two graph types, however, differ in their representation of data values. Bar graphs contain horizontal or vertical bars to show quantity and are used for numerical comparison between different categories. In line graphs, the relation between measures is symbolized by means of a line representing functional relationships or time-series data.

Much research in recent years has focused on the skills needed to successfully use graphs, including interpretation and construction. Interpretation usually refers to the ability to encode and understand the visual features of the graph and relate this information to the real world (Bertin, 1983; Shah & Hoeffner, 2002). While graph interpretation has received a good deal of research attention (for reviews see Glazer, 2011; Shah & Hoeffner, 2002), only a few studies focused on graph construction (Hattikudur et al., 2012; Mevarech & Kramarski, 1997; Wavering, 1989). Constructing graphs involves "going from raw data (or abstract function) through the process of selection and labeling of axes, selection of scale, identification of unit, and plotting" (Leinhardt, Zaslavsky, & Stein, 1990, p. 12). According to Leinhardt et al. (1990), construction differs considerably from interpretation because students have to create something new. Constructing an external representation involves a wide range of cognitive processes, for example, examining one's own ideas, re-ordering information, and translating information from one modality into another (Cox, 1999).

In a series of studies, Kozma and Russell (1997, 2005) and Kozma et al. (2000) investigated scientists' and learners' use of scientific representations and concluded that representational competence, including interpreting and constructing representations such as graphs, is crucial for developing a deeper understanding of scientific content. Originally conceptualized in the domain of chemistry, the construct of representational competence has gained attention in other domains, including biology (Nitz et al., 2014; Treagust & Tsui, 2013). Treagust and Tsui (2013) utilized Ainsworth's (1999) functional taxonomy of multiple external representations (MERs) to argue that using MERs can support learning in biology in various ways. In keeping with this perspective, graphs can be used, for example, to deepen conceptual understanding of complex biological principles in areas such as ecology or evolution.

Although interpretation is clearly critical to science learning, it has been emphasized that the process of generating representations has major learning and motivational benefits. In this regard, Ainsworth, Prain, and Tytler (2011) argued that creating visualizations such as graphs in science class (a) enhances engagement, (b) deepens students' understanding of conventions and purposes of scientific representations, (c) reinforces students' scientific reasoning, (d) helps students organize and expand their knowledge, and (e) allows students to exchange and clarify meanings between peers. Even though researchers in science education nowadays broadly agree that creating graphs and other graphical representations is a key ability in science education, in reality, it appears challenging for learners of different ages. Students commonly make systematic errors and hold alternative conceptions when it comes to constructing a graph and plotting data (Berg & Smith, 1994; Lai et al., 2016; Mevarech & Kramarski, 1997; Tairab & Khalaf Al-Naqbi, 2004). Based on an analysis of first-year university science students' abilities to construct graphs, von Kotzebue, Gerstl, and Nerdel (2015) concluded that many misconceptions and errors in graphing tasks seem to persist through secondary school and into university. In response to findings such as these, a growing body of science education literature exists on instructional practices that may advance graphing abilities.

Considering the situated and highly contextualized nature of scientific graphs, some argue that graphing skills should be explicitly fostered in science instruction (Glazer, 2011; Shah & Hoeffner, 2002; Szyjka, Mumba, & Wise, 2011; Tairab & Khalaf Al-Naqbi, 2004). Several authors stress the importance of the role of the teacher in this process, pertaining to scaffolding and metacognitive guidance in reasoning with graphs. According to Kramarski and Mevarech (2003) and Kramarski (2004), for example, students should receive clear strategies for solving graphing tasks.

Another key instructional feature found in the literature states that graphing activities should mirror authentic scientific practices (Bowen & Roth, 2005; Wu & Krajcik, 2006a, 2006b). To that end, students should be able to analyze, interpret, and visualize data they collected as part of a scientific inquiry environment.

Since scientific practices are iterative and social in nature, learning environments should also enable students to construct graphs collaboratively with the aim of making their displays increasingly convincing (Roth & McGinn, 1997, 1998; Wu & Krajcik, 2006b). One way to realize this educational goal is through small group or whole-class discussions, in which students learn to evolve graph-related practices through feedback from their classmates (Roth & McGinn, 1998).

Another instructional approach to both engaging students in authentic graphing practices and improving students' understanding of graphs is using computer-based tools and learning environments to visualize data (Roth & McGinn, 1998; Tairab & Khalaf Al-Naqbi, 2004). These tools allow students "to quickly modify the conditions of plots, test different hypotheses about relationships between dependent and independent variables, and change and test parameters of model equations" (Roth & McGinn, 1998, p. 53).

Teachers' Beliefs and Motivation

A variety of theoretical frameworks and methodologies in the teacher belief literature makes defining beliefs a challenging task (Jones & Carter, 2007; Pajares, 1992). It is widely acknowledged that beliefs are developed based on experiences and therefore highly personalized and evaluative in nature (Kagan, 1992; Nespor, 1987). However, opinions differ when it comes to, for example, the nature of the relationship between beliefs and knowledge and to the question of whether and to what extent beliefs influence actual behavior. Luft and Roehrig (2007) concluded that it is important to clarify the nature of the beliefs being examined. The concept of belief in the current study is used to characterize teachers' understandings and assumptions about phenomena, people, and objects felt to be true and affecting their planning and actions (Richardson, 1996; Voss, Kleickmann, Kunter, & Hachfeld, 2013). This definition implies the nature of beliefs as having two important aspects. First, teachers hold a wide and complex spectrum of beliefs. Calderhead (1996) differentiated between five areas of teachers' beliefs: beliefs about learners and learning, beliefs about teaching, beliefs about the subject, beliefs about learning to teach, and beliefs about the self and the role of teaching. These more general educational beliefs are also intertwined with domain-specific beliefs. For science teachers in particular, research studies have focused on beliefs including those about the teaching and learning of science (Bryan, 2003; Levitt, 2002; Tsai, 2002), and nature of science (Akyol, Tekkaya, Sungur, & Traynor, 2012; Irez, 2006; Zeidler, Walker, Ackett, & Simmons, 2002) or inquiry (Lucero, Valcke, & Schellens, 2012; Luft, 2001; Wallace & Kang, 2004). Because teachers' beliefs are complex and intertwined, some researchers characterized their structure as systems (e.g. Bryan, 2003; Fives & Buehl, 2008; Wallace & Kang, 2004). According to Thompson (1992, p. 130), belief systems are comparable to cognitive structures in a conceptual domain, being "dynamic in nature, undergoing change and restructuring as individuals evaluate their beliefs against their experience".

These experiences may differ depending on teachers' demographics and teaching background. In fact, previous research indicated that the personal characteristics of teachers appear to be associated with their beliefs. For example, based on analyses of teacher portfolios and interviews, Breslyn and McGinnis (2012) found the discipline in which secondary teachers taught a major influence on participants' beliefs in the area of inquiry learning. One explanation for this effect is that secondary teachers belong to distinctive subject subcultures characterized by differing beliefs, norms, and practice influenced by the nature of the parent discipline (Grossman & Stodolsky, 1995; Stodolsky & Grossman, 1995).

This has also been shown in the area of MERs. McElvany et al. (2012) found that geography or biology teachers expressed stronger beliefs in the utility of instructional pictures and were more self-efficacious compared with German language teachers. In addition to the teaching subject, teaching experience (Alger, 2009; Martínez, Sauleda, & Huber, 2001) is associated with effects on teacher beliefs. These and other characteristics may be considered influential variables to study differences in teacher beliefs.

A second important aspect of the nature of beliefs is that teachers' beliefs influence their planning, thoughts, and decisions in the classroom (Kagan, 1992; Mansour, 2009; Pajares, 1992). Beliefs serve as filters through which individuals process new information and thereby shape the interpretation of events and affect subsequent actions (Pajares, 1992). Hence, Pajares (1992) referred to beliefs as the "best indicators of the decisions that individuals make throughout their lives" (p. 307). Over the past decades, much research explored the relationship between teacher beliefs and classroom practices (Beck, Czerniak, & Lumpe, 2000; Brickhouse, 1990; Fang, 1996; Fitzgerald, Dawson, & Hackling, 2013; Haney, Lumpe, Czerniak, & Egan, 2002; Hashweh, 1996; Lotter, Harwood, & Bonner, 2007; Lucero et al., 2012; Ozel & Luft, 2013; Tsai, 2007; Verjovsky & Waldegg, 2005). For example, Tsai (2007) found a coherence between science teachers' beliefs and their instructional practices. Results of an in-depth study of three secondary science teachers by Lotter et al. (2007) suggested that teachers' core teaching conceptions (conceptions of science, their students, effective teaching practices, and the purpose of education) influence teachers in designing and performing scientific inquiry-based instruction.

In our study, we focus on biology teachers' beliefs regarding graph construction. Existing research in the domain of text-picture integration found that teachers' beliefs about the use of visual representations are linked to instructional behaviors and to students' engagement to learn from texts with visual representations (Schroeder et al., 2011). For example, the belief that students should be taught clear strategies on how to learn from texts with visual representations was positively related to the amount of time teachers spent discussing and reviewing texts containing visual representations when they used such texts in their lessons (Schroeder et al., 2011).

Furthermore, teachers' intrinsic motivation had an effect on the use of representations in class (McElvany et al., 2012). In general, intrinsically motivated people engage in a certain activity because they enjoy spending time on it and because they are interested in the activity (Deci, 1971; Ryan & Deci, 2000). This then often results in sustained long-term engagement. In educational research, teachers' motivation has been related both to teachers' instructional practices and to students' motivation and is therefore considered an important factor in teaching contexts (e.g., Kunter et al., 2008). In the area of representations, higher motivated teachers appear to more often use texts with visual-graphical representations in their instruction (McElvany et al., 2012).

Based on our review of the literature and these studies in particular, we think that access to information about teachers' beliefs and motivation regarding graph construction is valuable for science educators and can guide the design and evaluation of biology teacher education programs and professional development activities regarding graphing.

Purpose

Graphing is becoming an essential part of the science curriculum. While much research has focused on student conceptions and abilities in the area of graphical representations, only a few studies have investigated how teachers think about and use graphical representations in the classroom. The present study provides insights into the beliefs and motivation of German secondary biology teachers regarding graph construction. The study addressed the following research questions:

1) What are German secondary biology teachers' instructional beliefs and motivation in the regarding graph construction?
2) How do these variables vary in terms of teaching and research background?
3) Do teachers' beliefs and motivation regarding graph construction relate to self-reported instructional practices in this area?

Methods

This study was a survey of German secondary biology teachers about their beliefs, motivation, and self-reported practices regarding graph construction in biology class.

Measures

With this survey, we targeted (1) teacher demographics and teaching background, (2) teacher beliefs and motivation, and (3) the self-reported use of instructional activities and practices in the area of graph construction. For instrument development, we surveyed existing instruments, chose appropriate items and created new items as necessary. The overall 22 items on graph construction were reviewed by a panel of biology educators and a biology teacher ($N = 6$) to ensure content validity. Some minor wording issues and the order of some items in the questionnaire were revised based on the feedback. The following sections describe the survey in detail.

Teacher Demographics and Teaching Background. We collected information about participants' demographics and teaching background. Since teachers in Germany teach two subjects, we asked them to specify their second subject using a multiple choice question. Since authentic research experiences are considered an important factor in graphing, we asked the respondents to indicate whether or not they had research experience including pursuing a master or doctoral thesis in the natural sciences beyond the practical training in university.

Teacher Beliefs and Motivation. We adapted scales from an existing questionnaire assessing biology, geography, and German language teachers' beliefs about learning from instructional pictures (McElvany et al., 2012; Schroeder et al., 2011). The original scales had good reliabilities with Cronbach's alpha coefficients above 0.70. We changed the wording to reflect graph construction beliefs and motivation and created the following four scales:

- *Providing strategies* measured the belief that teachers should teach clear strategies for constructing graphs.
- *Explicit instruction* measured the belief that graph construction should be explicitly practiced in biology class.
- *Difficulty* was concerned with the belief that constructing graphs in biology class is complicated and teachers therefore feel uncertain to teach this aspect in class.
- *Motivation* measured teachers' enjoyment when constructing graphs.

Table 1 provides the number of items and sample items of the scales. Each item was to be rated on a 4-point Likert-type scale, ranging from 1 (strongly disagree) to 4 (strongly agree). Statistical analyses showed satisfying instrument quality in a pilot test with a sample of 46 biology teachers (48% female; $M_{age} = 41.2$, $SD_{age} = 12.2$). A confirmatory factor analysis with intercorrelated factors in the final study showed acceptable model fit ($\chi 2 = 114.896$, df = 84, $p = .014$, CFI = .938, RMSEA = .072). The internal consistencies of the four scales measured by Cronbach's alpha ranged from satisfying to high (see Table 1).

Table 1 Teacher beliefs and motivation: number of items, sample items, and reliability of the scales

Scale	Number of items	Sample item	α
Providing strategies	4	Biology teachers should provide students with clear strategies that they could apply when constructing graphs.	.77
Explicit instruction	4	It is important to explicitly practice constructing graphs in biology class.	.81
Difficulty	4	…constructing graphs in biology class is hard to teach students.	.86
Motivation	3	I enjoy constructing graphs in biology class.	.89

Teachers' Self-Reported Instructional Practices. Since we could not find an existing instrument assessing the frequency of different instructional activities and practices regarding graph construction, we designed seven items based on the reviewed literature on graphing and our own teaching experiences (see Table 6). The goal was to cover a broad range of instructional activities. Participants indicated how often (1 = *never*, 2 = *rarely*, 3 = *sometimes*, 4 = *often*) they use these practices in biology class.

Data Collection

As a first step, we sent a letter to the principals of secondary schools (academic track, *Gymnasium*) of four different states in Germany. The letter contained details about the study and invited biology teachers to participate voluntarily. A total of 80 teachers responded to our letter. Each teacher received a package containing the instruments and specific written instructions on how to carry out the survey. Teachers were instructed to respond to the items as honestly as possible to encourage realistic ratings. It was emphasized that the questionnaire was not a test, there were no wrong answers, and that the data would not be analyzed individually. We included pictures of a line and a bar graph at the beginning of the instrument to ensure respondents' understanding of the type of graphical representation addressed in the survey. Seventy-one completed surveys were returned to the first author.

Participants

In the final study, the self-report instrument was completed by 71 teachers (56% female) aged 27 to 62 (M = 45.3, SD = 10.4). All participants taught biology and an additional subject in different urban or rural secondary schools (academic track, *Gymnasium*) in grades 10 to 13 (age 15–19) in four different states of Germany. The levels of teaching experience varied from 1 to 40 years with an average of 17.5 years.

Data Analysis

We calculated the means and standard deviations for the teacher beliefs and motivation scales. Since the scales were not normally distributed, we calculated Spearman's coefficients to determine the relation between variables. We used t tests that are considered robust to the assumption of normality to explore differences between groups of teachers.

Prior to analysis, the teaching subject other than biology, was coded into two categories (1 = physics, chemistry, or mathematics; 0 = all other subjects), as was the teachers' research experience (1 = research experience in the natural sciences; 0 = no research experience beyond the practical training in university). The data were analyzed using SPSS 21.0.

Results

As shown in Table 2, the means of teachers' beliefs and motivation scales were between M = 1.88 (SD = 0.58) and M = 3.13 (SD = 0.59) on the four-point scale.

Table 3 shows the correlation matrix for the scales. There was a significant association between motivation and both explicit instruction and difficulty. Thus, teachers who enjoy constructing graphs tended to emphasize the explicit practice of graph construction in biology class. Teachers who thought that constructing graphs in biology instruction is complicated were less motivated to construct graphs with their students. Furthermore, there was a significant correlation between providing strategies and explicit instruction.

Regarding group differences in teachers' beliefs and motivation, *t* test results suggested significant differences between teachers that teach biology in combination with natural science or mathematics and teachers that teach biology in combination with other subjects like history or languages (Table 4). Participants teaching biology in combination with a natural science or mathematics tended to enjoy constructing graphs in biology class more, $t(66) = -2.00$, $p < .05$, $d = .50$, and perceived this aspect of instruction as less difficult, $t(69) = 2.51$, $p < .01$, $d = .68$.

An independent *t* test was also conducted to determine whether there was a significant difference between the teachers with and without research experience in natural sciences (Table 5). The results suggested a significant difference between the two groups concerning their motivation. Participants with science research experience enjoyed graph construction in biology class more than participants without science research experience, $t(65) = 2.95$, $p < .01$, $d = .75$, and also perceived this aspect of instruction as less difficult, $t(68) = -2.47$, $p < .05$, $d = .62$.

There was no significant association between beliefs and motivation and teaching experience.

To answer the third research question, we analyzed the self-report on instructional activities. Table 6 presents descriptives and percentages of practices related to graph construction in biology class.

Table 6 reveals that *creating graphs using provided data*, *creating graphs using self-collected data*, and *students copying graphs from the blackboard* received the highest means (2.76, 2.67, and 2.58, respectively). The latter two deviated more from the mean, indicating that teachers' self-reported practices were more diverse.

The practices *creating graphs based on students' own hypotheses*, *discussing self-generated graphs in small groups*, *creating graphs on the computer*, and *revising self-generated graphs based on feedback* received lower means (2.2, 2.1, 1.9, and 1.8, respectively). The ratings of the discussion item were widely distributed, with 7% of teachers using this practice frequently, while more than two-thirds indicated that they rarely or never did so. The least common practice was *revising self-generated graphs based on feedback*. It is notable that about 80% of participants never or rarely implement this activity in biology class.

Table 2 Means and standard deviations of the scales ($N = 71$)

Scale	*M*	SD
Providing strategies	3.05	.47
Explicit instruction	3.13	.59
Difficulty	1.88	.58
Motivation	2.89	.70

Table 3 Intercorrelations of the teacher scales ($N = 71$)

Scale	1.	2.	3.
1. Providing strategies	1		
2. Explicit instruction	.48**	1	
3. Difficulty	− .02	− .32**	1
4. Motivation	.07	.38**	− .33**

**p* < .05. ***p* < .01

Correlation coefficients were calculated to explore the relation between teachers' beliefs and motivation on the one hand and self-reported classroom practices on the other hand (Table 7).

Several teacher variables were associated with self-reported teaching practices. Teachers who thought that graphing should be explicitly practiced in biology class reported letting students create graphs using self-collected data more frequently. The higher the perceived difficulty of graph construction the less they reported letting students discuss their own graphs in small groups, revise their graphs based on feedback, and create graphs using a computer. Teachers' motivation was significantly positively correlated to letting students create graphs using self-collected data, discuss their own graphs in small groups, revise their graphs based on feedback, and create graphs using a computer.

Discussion and Educational Implications

The purposes of this study were to explore biology teachers' beliefs and motivation regarding graph construction and investigate how these beliefs and motivation vary in terms of teaching and research background and how they relate to self-reported instructional graph construction practices in class.

Table 4 Differences in beliefs and motivation of teachers with different teaching subjects

Scale	Subjects	*n*	*M*	SD	*t*	df	*d*
Providing strategies	0	42	3.01	.49	− .83	69	.25
	1	29	3.11	.45			
Explicit instruction	0	42	3.04	.56	− 1.59	69	.39
	1	29	3.26	.63			
Difficulty	0	42	2.02	.58	2.51**	69	.68
	1	29	1.68	.54			
Motivation	0	40	2.76	.69	− 2.00*	66	.50
	1	28	3.10	.67			

0, biology as only science subject; 1, biology in combination with another science subject or mathematics

**p* < .05. ***p* < .01

Table 5 Differences in beliefs and motivation of teachers with and without own research experience

Scale	Research exp.	*n*	*M*	SD	*t*	df	*d*
Providing strategies	Yes	41	3.11	.51	1.07	68	.25
	No	29	3.00	.42			
Explicit instruction	Yes	41	3.19	.64	1.65	68	.44
	No	29	2.93	.52			
Difficulty	Yes	41	1.74	.60	−2.47*	68	.62
	No	29	2.09	.52			
Motivation	Yes	38	3.11	.71	2.95**	65	.75
	No	29	2.62	.60			

*$p < .05$. **$p < .01$

Firstly, we found that the teachers surveyed in this study were quite motivated and secure in their teaching of graph construction. They tended to believe that graph construction should be practiced explicitly in biology class and that students should learn clear strategies for constructing graphs.

With regard to our second question, we explored the differences between groups of teachers. Participants that taught a combination of biology and another science or mathematics rated their motivation and secureness higher than teachers that taught biology in combination with other subjects like history or languages (Table 4). We hypothesize that these findings reflect a difference in the number of learning opportunities for teachers. The practice in graphing and learning about corresponding instructional strategies might be more common in preservice and in-service teacher training for science and mathematics. Therefore, teachers that teach mathematics or another science subject in addition to biology would have more learning opportunities, which in turn could explain their feelings of motivation and confidence. This finding might be clarified in future research by documenting learning opportunities in the area of quantitative methods or data visualization in the subject-specific teacher education programs.

Table 6 Descriptives and percentages of self-reported classroom practices ($N = 71$)

Item	*M*	SD	Never %	Rarely %	Sometimes %	Often %
Students create a graph using provided data	2.76	.62	2.8	25.4	64.8	7.0
Students create a graph using data they collected	2.67	.78	5.7	34.3	47.1	12.9
Students copy a graph from the blackboard	2.58	.86	9.9	36.6	39.4	14.1
Students create a graph based on their hypotheses about biological relationships	2.18	.78	18.3	49.3	28.2	4.2
Students discuss self-generated graphs in small groups	2.14	.88	23.9	45.1	23.9	7.0
Students use a computer to create a graph	1.86	.72	32.4	50.7	15.5	1.4
Students revise self-generated graphs based on feedback from classmates	1.83	.77	38.0	42.3	18.3	1.4

Table 7 Intercorrelations between teacher variables and self-reported classroom practices ($N = 71$)

Classroom practices	Teacher beliefs and motivation			
	Providing strategies	Explicit instruction	Difficulty	Motivation
Students create a graph using provided data	.22	.23	− .22	.18
Students create a graph using data they collected	.23	.42**	− .17	.33**
Students create a graph based on their hypotheses about biological relationships	− .10	− .07	− .16	.15
Students copy a graph from the blackboard	.16	.20	.05	.19
Students discuss self-generated graphs in small groups	.11	.15	− .27*	.25*
Students revise self-generated graphs based on feedback from classmates	− .01	.03	− .25*	.31*
Students use a computer to create a graph	− .09	.03	− .20	.28*

*$p < .05$. **$p < .01$

T test analysis also indicated an effect of own research experience in natural sciences beyond practical training at university, for example, as part of a master or doctoral thesis (Table 5). Previous research did show that preservice teachers' understanding of data collection and visualization improved through designing and carrying out their own investigations (Morrison & McDuffie, 2009). Based on such findings, science educators recommended that science teacher education programs should incorporate activities in which preservice teachers improve their graphing knowledge and skills by means of exposure to authentic science activities or tasks (Bowen & Roth, 2005; Lunsford, Melear, Roth, Perkins, & Hickok, 2007; Szyjka et al., 2011). Lunsford et al. (2007) reported on the production of various inscriptions in a science teacher education course on scientific observation and guided inquiry. They found that the quantity as well as the quality of inscriptions created by preservice teachers increased after the teachers designed and completed their own investigations. Based on their findings, they recommended that this type of science teacher education program requires "multiple experiences, spanning multiple semesters, in which potential teachers of science are routinely expected to engage in authentic scientific activity and use of inscriptions to document and communicate" (Lunsford et al., 2007, p. 561). Considering our findings, we suggest expanding programs similar to the previous example by further investigating and addressing teachers' beliefs and motivation with regard to graphing as they might be relevant target variables for such programs.

To answer our third question, we explored which graph construction practices the participants report as frequently used, and related those practices to their beliefs and motivation. The teachers surveyed indicated they used some of the graph construction activities more frequently than others. On average, the construction of graphs using both provided and self-collected data was relatively common among the participating teachers. Yet, it is notable that few of the teachers let students engage in collaborative graphing activities, such as discussing self-generated graphs in small groups. Even fewer teachers challenged students to revise self-generated graphs based on feedback. These findings imply potentially limited opportunities for students to experience graphing as an authentic social and iterative practice. We wonder if teachers might focus their instruction more on the technical, cognitive aspects of graphing, like how to create a graph, and might not make their students aware of the contextualized nature of graphs in science, e.g., as reasoning and communication tools.

Another practice rarely reported was constructing graphs on a computer. About one-third of the participating teachers never use computers for graphing tasks. Generally, teachers experience external and internal barriers when using computers in class (Ertmer, 1999). External barriers such as access to hardware and software depend on general school equipment. Internal barriers include personal variables, in our case, for example, a lack of knowledge about, or experience with, data visualization technologies or tools. To date, several digital resources exist that explicitly integrate quantitative methods and data visualization into learning environments and enable students to develop graphing skills while engaging in scientific reasoning. In the domain of biology, these resources include a wide range of materials (for a review, see Chen, Scott, & Stevens, 2018), such as instructional units that incorporate statistical modeling software like Excel (Malone, Schunn, & Schuchardt, 2018), modules on working with "messy" data (Schultheis & Kjelvik, 2015), video games with representational activities (Horwitz, 2013), or real-time interactive environments with complex, quantitative data analysis like cloud labs (Hossain et al., 2016).

Given the increasing importance of digital technologies in science research and education, including computerized testing, science teacher education programs should provide opportunities for teachers to work with data visualization technologies and tools, including identifying and discussing strengths and limitations of these technologies for science learning.

Our results also suggest that beliefs and motivation might be associated with how often teachers implement certain graph construction activities into their teaching practice. We found that teachers with stronger confidence and motivation report implementing graph construction activities more often in their instruction, especially with regard to collaborative activities. In light of the importance of these activities, as identified by previous research (Roth & McGinn, 1997, 1998; Wu & Krajcik, 2006b), we require more research on teachers' beliefs and motivation regarding graphing and the relationship to instructional practices. This could be accompanied by identifying contextual-institutional factors believed beneficial for this type of instruction.

Limitations and Future Research

This study could serve as a starting point for further examination of teachers' beliefs and motivation with regard to graph construction. There are, however, some important limitations concerning the study that merit consideration.

We relied on quantitative self-report surveys to investigate teacher variables, recognizing that this is only one of the numerous possible approaches. Even though assessing beliefs and motivational aspects with quantitative self-report surveys is very common, it has received criticism. Some have argued that participants may give socially desirable answers with self-report measures (Holtgraves, 2004). Although we explicitly instructed teachers to answer as honestly as possible and emphasized the anonymity of the survey as well as the fact that there were no wrong answers with regard to the questionnaire, we cannot completely rule out that participants presented their beliefs and motivation overly positively. Therefore, future research is needed to explore the consistency and generalizability of the results found in this study. Subsequent studies might include qualitative research methods such as interviews to provide deeper insights into teachers' beliefs and motivation with regard to graph construction. It would also be useful to compare teachers' perceptions of instructional activities with students' perceptions or observed behavior in class.

A potential problem regarding instrument quality pertains to discriminant validity of the belief and motivation scales. Correlation analyses indicated substantial relations between some of the scales. The directions of the correlations are conceptually reasonable and in line with results obtained with the original scales on teachers' beliefs and motivation in the area of text-picture comprehension (McElvany et al., 2012; Schroeder et al., 2011). Although this can be seen as an indicator for the validity of the adapted scales, these findings suggest a need to demonstrate and possibly improve the scales' discriminant validity in further studies.

Another limitation of the instrument is the validity and reliability of the single items used to assess the frequency of teaching practices. We designed items based on the reviewed literature and our own teaching experiences as we were not aware of any existing agreement regarding the structure for instructional graph construction activities. Although single-item measures are economic in covering a broad range of aspects, they have psychometric disadvantages, such as their failure to provide estimates of internal reliability, compared to scales. Nevertheless, the items gave us first insights into graph construction practices and could serve as a starting point for extended instruments or for multi-item scales in further studies.

The sample draws from secondary school biology teachers from four states in Germany. We cannot claim that the results generated in this study apply to science teachers in general. Furthermore, due to voluntary participation, it is possible that the sample included a comparatively large number of teachers having experience with or interest in graph construction. Further research is needed to replicate the results for different populations of teachers.

Furthermore, it would be interesting to expand this study to other disciplines. Since proficiency in graphing is a central element in several disciplines and subjects, we see the potential for a broader dialog aiming to improve graphing instruction through meaningful connections, especially for countries with individual science subjects like Germany.

We suggest that this line of research continues in order to explore the consistency and generalizability of the results found in this study and to further investigate how teachers think about and use graphs during instruction. Continued work in this area can potentially provide valuable information for the development of science teacher education programs and, ultimately, to improving students' learning with graphs in science class.

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