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Original Article

Nine years of online mentoring for secondary school girls in STEM: an empirical comparison of three mentoring formatsHeidrun Stoeger,¹  Michael Heilemann,¹ Tobias Debatin,¹ Manuel D. S. Hopp,² 
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Online mentoring can be useful for supporting girls in science, technology, engineering, and mathematics (STEM). Yet, little is known about the differential effects of various online mentoring formats. We examine the general and relative effectiveness of three online mentoring formats, one-on-one mentoring, many-to-many group mentoring, and a hybrid form of the two. All three formats were implemented in different years in the Germany-wide online-only mentoring program, CyberMentor, whose platform enables communication and networking between up to 800 girls (in grades 5–13) and 800 women (STEM professionals) each year. We combined longitudinal mentee data for all first-year participants ($N = 4017$ girls, $M_{\text{age}} = 14.15$ years) from 9 consecutive mentoring years to evaluate and compare the three mentoring formats. Overall, all formats effected comparable increases in mentees' STEM activities and certainty about career plans. However, mentees' communication behavior and networking behavior on the mentoring platform differed between the three formats. Mentees in the hybrid mentoring format showed the most extensive STEM-related communication and networking on the platform. We also analyzed the explanatory contributions of STEM-related communication and networking on interindividual differences in the developmental trajectories of mentees' STEM activities, elective intentions in STEM, and certainty about career plans, for each format separately.

Keywords: online mentoring; STEM participation rates; latent growth curve model; STEM communication; network analysis

Introduction

In Germany, women remain underrepresented in science, technology, engineering, and mathematics (STEM), especially in technical professions (14.1%) and in computer science (16.3%).^{1,2} Although many initiatives have sought to improve the situation,³ participation rates of women in STEM have risen only slowly.^{1,2} Many interventions focus on adults.⁴ However, starting interventions with this age group seems to be too late. Research shows that interest in STEM decreases during adolescence at the

latest—especially for girls^{5,6}—and that the decision to pursue a STEM-related degree is made most often toward the end of secondary education.⁷ Without access to proper interventions during childhood and adolescence, young women may very well have already formed stable non-STEM preferences by the time they make a decision about a college major. Therefore, interventions should start as early as possible, during secondary school years at the latest.

One measure that can be effective for increasing the STEM participation rates of women and for achieving desirable outcomes for girls on related

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variables in STEM is online mentoring.^{8–12} Mentoring has a wide variety of definitions.^{13–15} For our study, we define mentoring as a relatively stable relationship between one or more experienced persons (i.e., mentors) and one or more less experienced persons (i.e., mentees). This relationship is characterized by mutual trust and benevolence and aims at promoting the development and progress of the mentees.¹⁶ We define online mentoring as a special form of mentoring that exclusively or partly takes place online.¹⁷

We know from practice and research¹⁸ that mentoring typically has one of three formats: one-on-one mentoring, group mentoring, or a hybrid form of both. Yet, little is known about the relative benefits of each format in online mentoring for girls in STEM.¹⁸ Answers to the question are crucial for research and practice. If the three mentoring formats differ in their effectiveness, it is important to understand such differences and to take them into account when planning and implementing online mentoring for girls in STEM. If the formats do not differ in their effectiveness, knowing this would also be important. Those planning mentoring programs would have more leeway in specifying and implementing mentoring formats.

Therefore, we evaluated and compared the effectiveness of the three mentoring formats in a 1-year online-only mentoring program in STEM for girls enrolled in secondary education in Germany.^a The aim of the program—CyberMentor—is to increase participation of women in STEM. The program's mentoring outcomes are the frequency of STEM activities, elective intentions in STEM (i.e., the intention to make STEM-related decisions such as choosing to major in a STEM subject), and certainty about career plans. These outcomes are related to later real-life choices about college majors and professions (Ref. 19 and Stoeger *et al.*, work in progress). The mentors are women who are working in a STEM profession and have a college degree in STEM. CyberMentor's online platform enables communication among all of the up to 800 participating mentees and 800 mentors.

^aIn most German states, secondary education starts in the fifth grade and concludes in the twelfth or thirteenth grade.

During the 9-year-long mentoring cycles we examined (2009–2017), the program sequentially employed one-on-one mentoring (2009–2011), many-to-many group mentoring (2012), and hybrid mentoring (2013–2017) formats. In the many-to-many group mentoring format, three mentors and three mentees were combined in a mentoring community (without explicit one-on-one assignments between the mentees and mentors). In the hybrid mentoring format, two mentoring dyads were combined in one four-person mentoring community.

In a first step, we investigated the general and relative effectiveness of the three mentoring formats. To evaluate the mentoring formats' general effectiveness, we longitudinally analyzed whether each format led to improvements on the mentoring outcomes (i.e., on STEM activities, elective intentions in STEM, and certainty about career plans). To evaluate the mentoring formats' relative effectiveness, we examined whether the mentees' developmental trajectories on each of the three mentoring outcomes varied between the formats, or in other words, whether one or two of the three formats were more effective in increasing mentees' STEM activities, elective intentions in STEM, and certainty about career plans.

While the ways in which different mentoring formats might relate to program outcomes have not been clarified, research has shown that communication behavior and networking behavior in mentoring do influence mentoring outcomes.^{20–24} Therefore, in a second step, we investigated whether communication behavior and networking behavior on the online platform differed between the mentoring formats.

Even if mentoring is effective, there might be interindividual differences in the effectiveness. In other words, some mentees might benefit more from a program than others. In online mentoring for girls in STEM, communication behavior and networking behavior have been shown to explain interindividual differences in the effectiveness of mentoring.^{20,23} Therefore, in a third step, we investigated for each format separately whether there were interindividual differences in the developments of mentees' STEM activities, elective intentions in STEM, and certainty about career plans, and whether mentees' communication behavior and networking behavior on the mentoring platform

during the mentoring year explained interindividual differences in these developments.

Online mentoring for promoting girls in STEM

Online mentoring—also called electronic mentoring or e-mentoring¹⁷—has been characterized as a special form of mentoring in which at least parts of the communication take place electronically.²⁵ Some authors view online mentoring as, at best, an acceptable compromise solution when face-to-face mentoring is not possible.^{17,25–28} They stress disadvantages, such as participants' difficulties in filtering out social cues in computer-based communication,¹⁷ the need for high literacy skills,²⁶ or data-protection problems.^{27,28} Other authors stress advantages of online mentoring, such as its boundlessness and egalitarianism.²⁹ Research shows, furthermore, that online mentoring is particularly relevant for underrepresented groups or in fields where there is a shortage of adequate mentors^{30–32}—both of which are relevant aspects for mentoring girls and women in STEM. These findings and the fact that disadvantages of online mentoring can be overcome³³ suggest that the advantages of online mentoring can outweigh the disadvantages for certain groups of mentees.^{18,30,34} The case for online mentoring seems especially strong when it comes to mentoring of girls in STEM, as we will briefly illustrate.

Geography is a crucial factor in the case of STEM mentoring for girls. Appropriate mentors, namely, women who are graduate students or professionals in STEM,³⁵ are often not available in girls' local communities. While in many domains mentors' gender is of secondary importance for mentoring success,³⁶ evidence suggests otherwise for mentoring girls in STEM. In this context, women appear more effective than men as mentors.^{37–40} However, as workforce participation rates in STEM are low for women,^{1,2} finding suitable women mentors who live in mentees' immediate vicinity frequently becomes almost impossible in the case of STEM mentoring. Online mentoring enables mentoring relationships across large geographical distances and thus substantially increases the pool of potentially qualified women as mentors in STEM domains.

Another crucial factor in the case of STEM mentoring for girls is scheduling. Here, too, online mentoring offers an advantage by increasing scheduling

flexibility. Scheduling poses a challenge in mentoring programs in general. In some youth mentoring programs, the problem is mitigated by employing social workers as mentors, who then engage in mentoring during their regular worktime. This is difficult in STEM mentoring, in which mentors are often working fulltime in a STEM field^{37,38} and volunteering as mentors during their free time. Mentors working fulltime typically have inflexible schedules for volunteer mentoring. This makes it difficult for girls and their STEM mentors to arrange offline meetings. The problem is compounded by the aforementioned issue of geography, if the mentor and mentee live further away from each other. An exchange via email, chat, or video conferencing enables mentees and mentors to exchange ideas on a regular basis, even when mentors' and mentees' schedules and locations are quite different.

The spatial and temporal flexibility of online mentoring increases the probability that mentees and mentors will communicate regularly and to a sufficient extent. The extent and regularity of mentee-mentor communication are important prerequisites of successful mentoring.⁴¹ The provision of asynchronous communication (i.e., intermittent communication with a time delay; e.g., via emails, forum posts, and blogs) and synchronous (i.e., real-time communication; e.g., via chat and video conferencing) communication options⁴² allows mentees and mentors to communicate regularly and readily, despite having inflexible schedules and being separated by geographical distance.

Finally, a further advantage of online mentoring is that the same mentoring platform can be used to facilitate supplementary networking among mentees and mentors beyond a given mentoring dyad or community. Studies in graduate and postgraduate education in STEM have identified this feature as especially advantageous for underrepresented groups, such as women in STEM.⁴³ For girls, two considerations suggest why this feature should be especially advantageous.

First, the supplementary networking on the platform allows mentees to discover a variety of mentors who can act as role models.³⁵ As research on subtyping processes⁴⁴ has shown, the provision of plentiful, variegated higher status role models helps girls to see that their own mentor is not an exception to the rule. When an online mentoring

community offers a variety of female STEM professionals as role models, girls get to know their mentors as one of many women with successful careers in STEM rather than as an outlier. This can help to reduce stereotypes about STEM as being unfeminine.^{45–47} Findings support the notion that the provision of a variety of female STEM role models positively influences girls' STEM choices.⁴⁶

Second, through mentees' exchanges with other girls on the platform, they see that many girls of the same age are interested in STEM. Such a realization is often not possible in girls' local offline environments.²⁰ Research has shown that female peers can act as "social vaccines" who protect girls from negative influences on their STEM self-concepts. This positive inoculative effect on STEM self-concept can influence elective behaviors in the long run.^{35,48}

Different formats for online mentoring of girls in STEM

The effectiveness of online mentoring for increasing girls' and women's participation in STEM and related variables, such as elective intentions, STEM activities, or knowledge about STEM professions, has been supported by various studies (Refs. 8, 20, 23, 34, and Stoeger *et al.*, work in progress). Much of this research examines mentorship on the level of dyads, which constitutes one-on-one mentoring.⁴⁹ Some of these studies also consider formats involving more than one mentor or mentee, namely, collective or group mentoring.^{50,51} However, we do not know whether one of these formats—one-on-one mentoring or one of the various forms of group mentoring—is particularly effective for increasing participation rates of girls and women in STEM and related variables.¹⁸

From the multiple theoretical perspectives that have guided research on mentoring girls in STEM so far, both one-on-one and collective or group mentoring formats seem to have certain advantages. Much of this work has emphasized the role-model function of mentoring.⁵² The idea is that the mentor is a role model and projection of the self. Mentoring, therefore, helps girls to imagine themselves in the field of STEM in the future. Dasgupta's social-vaccine research³⁵ extends this approach to peer mentors and suggests that formats that enlist a small group of peers (i.e., group-mentoring formats) may be especially advantageous by affording a better

variety of potentially helpful role models. Another approach that signifies advantages of group mentoring is social networks theory⁵³ that emphasizes advantages of depth and breadth of mentoring relationships and interactions in mentoring.

In the following, we will describe one-on-one mentoring, group mentoring, and a hybrid form of one-on-one and group mentoring formats in more detail and discuss the possible advantages and disadvantages that each format could have in an online mentoring program for girls in STEM that facilitates both mentoring and supplementary networking among all participants (i.e., also among all mentees and mentors) on a virtual platform.

One-on-one mentoring refers to a one-on-one relationship between a less experienced person (i.e., a mentee) and a more experienced person (i.e., a mentor) that is intended to advance the personal and professional or academic growth of the less experienced individual.^{54,55} An advantage of one-on-one mentoring is the clear association between one mentee and one personal mentor. This facilitates the development of a relationship between mentee and mentor⁵⁶ and ensures that the mentor can focus their undivided attention on one mentee. Longitudinal studies,^{8,20,23} two of which made use of a waitlist control group,^{8,20} showed positive developments for girls in grades 5–13 who participated in a yearlong one-on-one online-only mentoring program in STEM on outcomes, such as STEM activities, knowledge about university studies and jobs in STEM, or academic elective intentions.

A potential disadvantage of one-on-one mentoring in the context of an online mentoring platform may be that the one-on-one focus might encourage lower levels of communication and networking with other platform participants. Supplementary communication and networking outside a given mentoring dyad have been shown to positively influence the effectiveness of online mentoring in STEM for girls.^{13,20,43} The aforementioned research confirming the effectiveness of one-on-one mentoring in an online context did not, however, consider whether mentees who extensively communicated with their mentors tended to communicate and network less with other participants outside the mentoring dyad on the platform.

As various forms of group mentoring exist, definitions of group mentoring vary considerably.^{18,57,58} The term *group mentoring* is used for contexts in

which one or more experienced person(s) (i.e., mentors) interact with one or more less experienced person(s) (i.e., mentees) with the intention of promoting the mentees' personal and academic growth. The terms *one-to-many*, *many-to-one*, and *many-to-many* mentoring distinguish different forms of group mentoring according to the number of participating mentees and mentors.⁵⁷ Only few studies on the effectiveness of group mentoring in STEM exist.¹⁸ These suggest that affinity-based group mentorship can be especially effective for underrepresented groups in STEM, such as girls and women.^{50,51} For example, group mentoring for women scholars has been shown to support skills, self-efficacy, and career satisfaction.^{59,60}

Research on the effectiveness of group mentoring for girls in STEM is sparse, and studies that compare different formats are lacking.^b However, research according to the social-vaccine³⁵ and the social-network paradigms⁵³ suggests that the many-to-many group mentoring format might be especially propitious for supporting girls in STEM. In many-to-many group mentoring, the multiperson mentoring format ensures that mentees will interact with a variety of participating girls and women. Within their own mentoring group, girls have access to various mentors (i.e., women who are successful in a STEM career). At the same time, they interact with other mentees who are also interested in STEM. Both types of group members can act as social vaccines that inoculate the girls against deleterious influences on their STEM self-concepts and mediated by this can positively influence the girls' commitments to pursue STEM careers.^{35,38,48}

An advantage of the many-to-many group mentoring format might also be that mentees can more easily find suitable communication partners, even in the event, for example, that additional commitments (such as an increased workload) temporarily prevent a certain mentor from engaging with a mentee. Yet, some research conducted outside the field of STEM suggests that fewer focused mentee-mentor relationships may also qualify as a disadvan-

tage of group mentoring formats,⁶¹ as less intensive mentee-mentor relationships have been associated with fewer advantageous mentoring outcomes.⁶²

Hybrid forms of one-on-one mentoring and many-to-many group mentoring combine aspects of both formats. In hybrid mentoring, each mentee has a clearly assigned mentor who is primarily responsible for the mentee and who is available to that mentee as the main contact person; at the same time, several such mentoring dyads are combined in the sense of many-to-many group mentoring. To the best of our knowledge, only one study has compared one-on-one mentoring with a form of hybrid mentoring for girls in STEM.²³ In this study, girls participated in an online-only mentoring program in STEM that first offered a one-on-one mentoring format and then, after several years, changed to a hybrid mentoring format. Hybrid mentoring took place in four-person groups that consisted of two mentor-mentee dyads. In comparison to the earlier version of the program that employed one-on-one mentoring, the girls who participated in the hybrid mentoring format communicated more about STEM topics and made more use of networking opportunities on the platform outside of their mentoring relationships. Mentees in the hybrid format also reported increased elective intentions in STEM after 6 months of mentoring, while the mentees in the one-on-one format did not.

Current study

Research suggests that one-on-one, group, and hybrid mentoring formats can be effective.¹⁸ However, some of the relevant findings were not based on STEM mentoring; and empirical work has yet to address whether all three formats can be effective in supporting girls in STEM and whether there are differences in the relative effectiveness of the three formats. The goal of our study was, therefore, to investigate these research gaps for online mentoring for girls in STEM. To this end, we articulated three research aims that we investigated by looking at 9 consecutive year-long cycles (i.e., years) of a 1-year online-only mentoring program for girls in STEM. Their mentors were women with degrees in STEM and who were working in STEM fields. The specific mentoring formats under examination were one-on-one mentoring, many-to-many group mentoring, in which three mentors and three mentees constituted one mentoring community (without

^bOne study²³ compared one-on-one and group mentoring formats. However, the group mentoring format was a form of hybrid mentoring in which the groups consisted of two mentoring dyads. We report results of this study in the section on hybrid mentoring.

dyadic associations between the mentees and mentors), and a hybrid form, in which two mentoring dyads were combined into one four-person mentoring community. The three formats were implemented during different years of the same mentoring program that also facilitated supplementary networking with mentees and mentors outside of the mentoring dyad and mentoring communities. From 2009 to 2011, the program implemented one-on-one mentoring; in 2012, the program implemented many-to-many group mentoring; and from 2013 to 2017, the program implemented the hybrid mentoring form. Over the course of the 9 examined years, the program only altered the mentoring format, and the approach to recruiting mentees and mentors remained unchanged.

Aim 1

Our first aim was to examine the general and relative effectiveness of the three mentoring formats with regard to three mentoring outcomes: STEM activities, elective intentions in STEM, and certainty about career plans. We focused on these three outcomes as they are related to later real-life choices about college majors and professions,^{19, 63–68} and therefore to the long-term goal of the program under investigation of increasing the participation rates of girls and women in STEM. We measured the three outcomes at multiple points in time, namely, just before commencement of each mentoring year, 6 months after its commencement, and at its end. This makes it possible to study developmental trajectories. Increases in mentees' STEM activities, elective intentions in STEM, and certainty about career plans would suggest that mentoring has been effective.

We investigated the *general effectiveness* of the three mentoring formats by analyzing whether each format led to positive changes in mentees' STEM activities, elective intentions in STEM, and certainty about career plans. We investigated the *relative effectiveness* of the three formats by analyzing whether the developments of the mentoring outcomes were comparable or differed between the three mentoring formats. Should the investigation indicate, for example, that all three mentoring formats were to lead to increases on the three outcomes (i.e., general effectiveness) but that the increases in the developmental trajectories of the three mentoring outcomes were greater for one or two of the formats

(i.e., relative effectiveness), this would tell us that one of two formats had been more effective. Such a finding would inform decisions about mentoring formats for comparable programs in the future.

Aim 2

Our second aim was to investigate whether communication and networking of mentees with other participants (i.e., with all mentees and mentors across the entire mentoring program) differed for the three mentoring formats. We investigated differences between the formats concerning these aspects, as previous research—within and outside the field of STEM—has characterized both communication behavior and networking behavior as important characteristics of successful mentoring.^{20–24,49,69}

Research on community-based youth mentoring programs outside the field of STEM reported positive relationships between the amount of mentor–mentee communication and ratings of the programs' benefits for participating youths.²² Moreover, the extent to which the communication actually focuses on program-relevant contents appears important.²¹ Earlier research on an online-only mentoring program for girls in STEM found a positive relationship between the effectiveness of STEM mentoring and the extent to which participants focused their communication on STEM contents.²⁰ In our study, we investigated communication behavior by analyzing mentees' email messages and forum posts on the platform.

For each mentoring format, we assessed the amount of communication by recording the overall number of words mentees wrote in their emails and forum messages. We assessed the STEM-relatedness of the communication by recording the percentage of STEM words in the emails and forum messages. Research from various disciplines—in personality psychology⁷⁰ and education,⁷¹ for example—indicates a consistent relationship between the frequency with which individuals write or speak about specific topics and their perceptions of the importance of those topics.

Various studies outside the field of STEM have found positive relationships between the size of mentees' and mentors' networks and positive mentoring outcomes.^{24,49,72,73} For example, in a longitudinal study on workplace mentoring, network size was the best predictor of mentees' career success.²⁴ Besides the size of mentees'

networks, the characteristics of a network—who is networking with whom—seem to play a role in effective mentoring.⁴⁹ Research on networking among academics in economics, for example, illustrated that outcomes depended not simply on the amount of networking taking place, but also on the extent to which a given academic's network partners were themselves also interconnected.⁷⁴

For each mentoring format, we assessed the overall number of mentees' communication partners (i.e., mentees' mentee contacts and mentees' mentor contacts) on the platform as well as the number of mentees' communication partners with whom one or more STEM-related emails were exchanged. We also assessed two characteristics of mentees' networks. First, we assessed the overall interconnectedness between mentees' communication partners (i.e., the extent to which a mentee's contacts were themselves connected with one another). This characteristic is referred to as local clustering in network research and has been shown to influence mentoring effectiveness in other studies.⁷⁴ Second, in light of the findings on mentoring communication reported above,^{21,22,69} we assessed the STEM-related interconnectedness of mentees' communication partners by calculating the local clustering of their STEM-related email communication networks.

Aim 3

Even when mentoring formats are effective, their effectiveness can vary from one participating mentee to the next. Knowledge about variables that explain such interindividual differences can lead to improvements in the planning and implementation of mentoring programs. Therefore, our third aim was to examine the influence of communication and networking (as defined for Aim 2) on interindividual differences in the development of the three mentoring outcomes—STEM activities, elective intentions in STEM, and certainty about career plans—for each of the three mentoring formats, respectively. In light of the justifications of Aims 1 and 2, communication behavior and networking behavior are likely also explain interindividual differences in the effectiveness of online mentoring in STEM for girls.^{21,24,72,75,76}

We, therefore, also assessed—for each mentoring format separately—whether (1) amount of commu-

nication, (2) STEM-relatedness of communication, (3) overall number of mentees' communication partners, (4) number of mentees' STEM-related communication partners, and (5) STEM-related interconnectedness of mentees' communication partners explained differences in mentees' increases in STEM activities, elective intentions in STEM, and certainty about career plans over the mentoring year. In other words, we assessed whether the five measures of mentees' communication behavior and networking behavior explained variances in the developmental trajectories of the three mentoring outcomes.

Study setting

The three research aims were investigated within the online-only mentoring program CyberMentor. The long-term goal of CyberMentor is to increase the participation rates of girls and women in STEM as these are still quite low in Germany.^{1,2,77} The program tries to reach this goal by facilitating improvements on outcomes, such as STEM activities, elective intentions in STEM, and certainty about career plans that are related to later real-life choices about studying and working in STEM. As many as 800 mentees and 800 mentors from throughout Germany participate in the program every year. Mentees are girls enrolled in secondary education in Germany (i.e., in grades 5–13) and thus between the ages of 11 and 18 years. The mentors are women who have a college-level STEM degree and are working in a STEM profession or on a graduate-level STEM degree. The program is free of charge for the girls; the mentors volunteer their time.

Program participants communicate on a secure, members-only online platform via email, chat, and forums. Mentees and mentors commit to communicate with each other for at least 30 min a week. Mentees and mentors communicate about various topics, including STEM, curricular and extracurricular activities, and their everyday experiences. All participants spend at least 1 year in the program. At the end of each mentoring year, mentees and mentors can register to participate for an additional year. This study looked only at those mentees who were participating in CyberMentor for the first time.

Different mentoring formats were implemented during consecutive 1-year mentoring cycles (i.e., years; for more details, see Method section). From 2009 to 2011, the program offered only

one-on-one mentoring. Each mentee was matched with a personal mentor. In 2012, the program changed the mentoring format to many-to-many group mentoring. Three mentees and three mentors were matched into a mentoring community. Within the six-person communities, there was no one-on-one mentee-mentor matching. From 2013 to 2017, a hybrid mentoring format was used that combined one-on-one and many-to-many group mentoring. Two mentoring dyads are combined to form four-person communities; within the four-person communities, the dyadic mentee-mentor relationships are maintained. All three mentoring formats also offered supplementary communication and networking options for all participants. In other words, mentees and mentors were also able to communicate with mentees and mentors on the platform who were not necessarily part of their mentoring dyad or community.

Method

Sample and procedure

For our study, we combined data from 9 mentoring years (2009–2017) for 4017 mentees who were in their first year of program participation. Data for mentees' subsequent years of participation were not included. From 2009 to 2011, the program used a one-on-one mentoring format ($n = 2158$ first-time mentees). During the 2012 mentoring year, the format was changed to many-to-many group mentoring. Six-person communities were formed consisting of three mentees and three mentors without explicit one-on-one assignments ($n = 231$ first-time mentees). From 2013 to 2017, the program applied a hybrid mentoring format that combined one-on-one mentoring and many-to-many group mentoring. Four-person communities were formed consisting of two mentoring dyads; each dyad reflected a one-on-one mentor-mentee assignment ($n = 1628$ first-time mentees). The 4017 girls (age: $M = 14.15$ years, $SD = 2.12$; one-on-one: 14.36 (2.19), many-to-many: 14.79 (1.89), hybrid: 13.84 (2.26)) were enrolled in university-track secondary education across Germany and thus in grades 5–13. The women who volunteered as mentors (age: $M = 32.30$ years, $SD = 8.52$; one-on-one: 32.87 (8.36), many-to-many: 32.54 (8.51), hybrid: 31.47 (8.68)) had all earned a university-level degree in a STEM subject. At the time of mentoring, the mentors were working in STEM. They

were working on a graduate-level STEM degree or doing postgraduate STEM research (47.6%; one-on-one: 46.8%, many-to-many: 44.0%, hybrid: 49.6%), working in another research capacity at a university or research institution in a STEM field (6.4%; one-on-one: 7.1%, many-to-many: 6.8%, hybrid: 5.6%), or working in corporate STEM contexts (45.9%; one-on-one: 46.2%, many-to-many: 49.1%, hybrid: 44.8%). Most mentors worked in the field of science (43.8%; one-on-one: 42.6%, many-to-many: 47.4%, hybrid: 44.7%), followed by engineering (35.2%; one-on-one: 37.1%, many-to-many: 41.1%, hybrid: 31.2%), information technology (26.9%; one-on-one: 28.7%, many-to-many: 27.0%, hybrid: 24.3%), and mathematics (13.7%; one-on-one: 12.8%, many-to-many: 18.0%, hybrid: 13.8%).

All mentees were asked to fill out an online questionnaire before beginning their first mentoring year, after the first half of the mentoring year, and at the end of the mentoring year. Three thousand four hundred and seventy-eight mentees completed the questionnaires for at least one of the three time points. Three thousand three hundred and ninety-six mentees (97.6%) filled out the questionnaire at time point 1; 1720 mentees (49.5%) did so at time point 2; and 1243 mentees (35.7%) did so at time point 3. For 3484 mentees, data about their platform communication (emails and forum posts) were available. For 3220 mentees, both questionnaire and communication data were available.

Measures

Questionnaires.

STEM activities. We assessed participants' frequency of STEM activities with a nine-item scale that is being validated in a recent study (Stoeger, *et al.*, work in progress). Respondents indicated on a Likert-type scale how often they were typically engaged in different STEM activities. The endpoints are formulated as statements, for example, ranging from "I have never read a book about STEM before," to "I have read books about STEM very often." During the years of the one-on-one mentoring format, a 4-point Likert-type scale was used; during the years of the group and hybrid formats, a 6-point Likert-type scale was used. We rescaled the 4-point and 6-point versions of the scale into percentage scales to make them comparable. Rescaled values range from 0 to 100 for all formats and represent the percentage

of agreement with the statements. Cronbach's alpha was 0.81, 0.82, and 0.83 for the three time points.

Elective intentions in STEM. We assessed participants' elective intentions in STEM with a five-item scale that is being validated in a recent study (Stoeger, et al., work in progress). Respondents indicated on a 6-point Likert-type scale ranging from 1 (completely disagree) to 6 (completely agree) how well they could picture themselves choosing a university major in STEM, choosing a STEM subject for a track or course at school or in college, or pursuing a career in a STEM field. A sample item reads: "I can picture myself majoring in a STEM subject." Cronbach's alpha was 0.82, 0.84, and 0.88 for the three time points.

Certainty about career plans. We assessed participants' certainties about career plans with a 10-item scale⁷⁸ that is being validated in a recent study (Stoeger, et al., work in progress). Respondents indicated how certain they were about their future career plans on a 6-point Likert-type scale ranging from 1 (completely disagree) to 6 (completely agree). All items were worded without references to the STEM domain. A sample item reads: "I know quite well for which careers I am best suited." Cronbach's alpha was 0.91, 0.92, and 0.93 for the three time points.

Communication behavior. CyberMentor participants communicated with one another via internal forum, email, and chat functions. We assessed the extent and STEM-relatedness of mentees' online platform communication via word count and the percentage of STEM words, respectively. We did not include the mentees' chat messages in our analyses, because the overall percentage of STEM-related chat messages was negligibly low.

Word count. We assessed the overall number of words that mentees wrote in their forum and email messages using the text-analysis program LIWC (Linguistic Inquiry and Word Count).⁷⁹

Percentage of STEM words. We assessed the percentage of STEM words in mentees' forum and email messages with the text-analysis program LIWC (Linguistic Inquiry and Word Count)⁷⁹ and a STEM-word dictionary consisting of 1926 words.⁸⁰ The LIWC software package counts the absolute number of words in a text and determines the percentage of STEM words in the text by comparing each word with the STEM-word dictionary.

Networking behavior. We used the following measures to assess the number of mentees' communication partners, the interconnectedness between mentees' communication partners (local clustering), and the STEM-related interconnectedness of mentees' communication partners (local STEM clustering).

Number of mentees' communication partners. We counted the overall number of mentees and mentors with whom each mentee exchanged at least one email reciprocally (i.e., sent an email and received a response email) as well as the number of mentees and mentors with whom each mentee exchanged reciprocally one or more STEM-related emails.

•*Mentor contacts.* The variable denotes the number of mentors with whom a mentee exchanged at least one email reciprocally.

•*Mentee contacts.* The variable denotes the number of mentees with whom a mentee exchanged at least one email reciprocally.

•*Mentor STEM contacts.* The variable denotes the number of mentors with whom a mentee exchanged at least one STEM-related email reciprocally.

•*Mentee STEM contacts.* The variable denotes the number of mentees with whom a mentee exchanged at least one STEM-related email reciprocally.

Interconnectedness of mentees' communication partners (local clustering). The variable denotes the extent to which a mentee's communication partners are themselves connected with one another. To measure the interconnectedness of mentees' communication partners, weighted local clustering coefficients were calculated for each mentee using the variables for mentee contacts and mentor contacts.⁸¹ Clustering coefficients are a measure of transitivity in a network, that is, of the number of a mentee's communication partners who also communicate with one another.⁸² For example, if a mentee has three communication partners, two of whom communicate with one another, the local clustering coefficient is 1/3, because one of a total of three possible communication paths between the mentee's communication partners is realized. In a communication network, such as the CyberMentor online platform, both the totality of communication paths (i.e., the edges) and the number of messages being exchanged along each edge (i.e., the weight of the edge) are known and can thus be taken

into account in the form of a weighted local clustering coefficient.⁸¹ If, for example, a mentee has three communication partners who exchange information with one another frequently, this mentee is assigned a higher weighted local clustering coefficient than another mentee who also has three communication partners, but whose communication partners exchange information with one another only rarely.

STEM-related interconnectedness of mentees' communication partners (local STEM clustering). The variable denotes the extent to which a mentee's communication partners relate to one another on the basis of the exchange of STEM-related emails. It is calculated in a manner analogous to the interconnectedness of mentees' communication partners but considers the reciprocal email communication paths for emails that contained at least one word from the aforementioned STEM word dictionary.⁸⁰

Data analysis

Our main analyses are based on the latent growth curve approach. In the latent growth curve approach—which is situated in the framework of structural equation modeling⁸³—a growth process of a variable repeatedly assessed at consecutive time points is modeled by two latent variables, the intercept factor and the slope factor. The intercept factor represents the initial level of the variable of interest at time point 1, while the slope factor represents the change of this variable over the assessed time points. Variances of these factors represent interindividual differences in initial level and in the amount of change, respectively. In extended growth models, the two factors can be regressed on other variables to investigate relationships with the individual growth trajectories. In the following, we describe the models we used to address our research questions.

Overview of analyses for investigating our research aims.

Aim 1. To evaluate the general effectiveness of the three mentoring formats, we first calculated unconditional linear latent growth curve models (i.e., models without covariates) for each format separately, using only the three consecutive measurements of each outcome (i.e., STEM activities, elective intentions in STEM, and certainty about career plans) to assess their growth trajectories over the course of the program. We thereby focused on

the slope factors as a measure of the amount of change in the outcomes. To compare the effectiveness of the different mentoring formats (i.e., their relative effectiveness), we calculated conditional linear latent growth curve models for a combined sample of all three formats by regressing the slope factors of the outcomes on dummy variables representing the different formats.

Aim 2. To compare the mentoring formats with respect to mentees' communication behavior and networking behavior, we used nonparametric Kruskal–Wallis tests as the residuals in ANOVAs were clearly not normally distributed and the variances differed by format.

Aim 3. To investigate the explanatory contribution of mentees' communication behavior and networking behavior on outcome development within each format, we regressed the slope factors on word count and percentage of STEM words as well as on the STEM-specific network variables (i.e., mentee STEM contacts, mentor STEM contacts, and local STEM clustering) using conditional growth models. In the conditional growth models, all predictors except the percentage of STEM words were log transformed because of the very high positive skewness of their distributions (>3.50).

Estimation of the growth models. The analyses were conducted with *Mplus* 6.⁸⁴ Missing data were handled using the full information maximum likelihood method, which is also appropriate for longitudinal studies with substantial attrition, as in our study.⁸⁵ For our latent growth curve models, which include the same outcomes at different time points as a part of the model, no further auxiliary variables were required.⁸⁵

The maximum likelihood estimator was used for all analyses. Model fit was assessed following the criteria of Ref 86. Therefore, a value close to 0.95 for the comparative fit index (CFI), a value close to 0.06 for the root mean squared error of approximation (RMSEA), and a value close to 0.08 for the standardized root mean squared residual (SRMR) were the cutoff criteria for assuming good model fit.

Results

All of the linear growth curve models showed good model fit according to every index we examined. Therefore, we only report the model fit of the worst-fitting model (i.e., the unconditional growth

Table 1. Descriptive statistics of the mentoring outcomes at the three time points (T₁ to T₃) separately for each mentoring format

	M			SD			Range
	T ₁	T ₂	T ₃	T ₁	T ₂	T ₃	
<i>One-on-one mentoring</i>							
STEM activities	52.48	56.30	57.35	19.35	19.45	19.36	0–100
Elective intentions in STEM	4.76	4.73	4.73	0.82	0.90	1.03	1–6
Certainty about career plans	3.62	3.77	3.90	1.05	1.10	1.09	1–6
<i>Group mentoring</i>							
STEM activities	59.51	61.70	63.56	16.94	16.45	16.45	0–100
Elective intentions in STEM	4.89	5.00	4.99	0.88	0.85	0.89	1–6
Certainty about career plans	3.61	3.73	3.95	1.14	1.18	1.20	1–6
<i>Hybrid mentoring</i>							
STEM activities	56.25	59.45	61.32	19.10	18.24	17.23	0–100
Elective intentions in STEM	4.76	4.76	4.70	0.84	0.88	1.01	1–6
Certainty about career plans	3.59	3.74	3.77	1.09	1.12	1.13	1–6

NOTE. Sample statistics are based on the full information maximum likelihood method.

model of STEM activities in one-on-one mentoring), which still showed a good model fit with CFI = 0.991, RMSEA = 0.076, and SRMR = 0.027.

Aim 1

For Aim 1, we investigated the general and relative effectiveness of the three mentoring formats for the three mentoring outcomes (i.e., STEM activities, elective intentions in STEM, and certainty about career plans). For each mentoring format, we will first report the analyses of its general effectiveness. We describe the development in unconditional growth models for STEM activities, elective intentions in STEM, and certainty about career plans and note whether interindividual differences between the growth trajectories were significant. We will then report the analyses of the models' relative effectiveness, by describing whether we found differences in the development of STEM activities, elective intentions in STEM, and certainty about career plans between the three mentoring formats. Table 1 shows the descriptive statistics for STEM activities, elective intentions in STEM, and certainty about career plans at the three time points for each mentoring format separately.

General effectiveness of the three mentoring formats for one-on-one mentoring.

STEM activities. In the unconditional growth model of STEM activities, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 5.12, P < 0.001$).

The scale mean increased from 52.64 to 57.76 according to the linear growth model. Interindividual differences between the growth trajectories were significant ($Var = 158.66, P < 0.001$).

Elective intentions in STEM. In the unconditional growth model of elective intentions in STEM, there was no mean growth over the course of the mentoring year as indicated by the nonsignificant mean slope ($M = -0.03, P = 0.180$). However, interindividual differences between the growth trajectories were significant ($Var = 0.21, P = 0.002$).

Certainty about career plans. In the unconditional growth model of certainty about career plans, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 0.29, P < 0.001$). The scale mean increased from 3.62 to 3.91 according to the linear growth model. Interindividual differences between the growth trajectories were significant ($Var = 0.72, P < 0.001$).

General effectiveness of the three mentoring formats for group mentoring.

STEM activities. In the unconditional growth model of STEM activities, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 4.07, P = 0.027$). The scale mean increased from 59.54 to 63.61 according to the linear growth model. Interindividual differences between the growth trajectories were not significant ($Var = -88.65, P = 0.514$).

Elective intentions in STEM. In the unconditional growth model of elective intentions in STEM, there was no mean growth over the course of the mentoring year as indicated by the nonsignificant mean slope ($M = 0.11$, $P = 0.183$). Interindividual differences between the growth trajectories were not significant ($Var = 0.20$, $P = 0.309$). The analysis included one extreme multivariate outlier (Cook's distance > 13); we excluded the case from the final analysis because of its inordinate influence on our estimates.

Certainty about career plans. In the unconditional growth model of certainty about career plans, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 0.32$, $P < 0.001$). The scale mean increased from 3.61 to 3.93 according to the linear growth model. Interindividual differences between the growth trajectories were not significant ($Var = 0.18$, $P = 0.660$).

General effectiveness of the three mentoring formats for hybrid mentoring.

STEM activities. In the unconditional growth model of STEM activities, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 5.13$, $P < 0.001$). The scale mean increased from 56.36 to 61.49 according to the linear growth model. Interindividual differences between the growth trajectories were significant ($Var = 107.06$, $P = 0.043$).

Elective intentions in STEM. In the unconditional growth model of elective intentions in STEM, there was no mean growth over the course of the mentoring year as indicated by the nonsignificant mean slope ($M = -0.04$, $P = 0.330$). Interindividual differences between the growth trajectories were also not significant ($Var = 0.20$, $P = 0.116$).

Certainty about career plans. In the unconditional growth model of certainty about career plans, there was mean growth over the course of the mentoring year as indicated by the significant mean slope ($M = 0.20$, $P < 0.001$). The scale mean increased from 3.60 to 3.80 according to the linear growth model. Interindividual differences between the growth trajectories were significant ($Var = 0.58$, $P = 0.001$).

Relative effectiveness of the three mentoring formats. We used dummy variables with changing mentoring formats as the reference group to com-

pare the effectiveness of the three formats in a combined sample. We started with one-on-one mentoring as the reference group in order to evaluate differences compared with group and hybrid mentoring. Then, group mentoring served as the reference group to analyze the missing comparison between group and hybrid mentoring. Despite the large sample size, we found no significant difference between any two formats in these models regarding the development of the three outcomes, that is, for STEM activities, elective intentions in STEM, and certainty about career plans.

Aim 2

For Aim 2, we investigated whether mentees' communication and networking with other mentees and mentors on the platform differed between the three mentoring formats. To analyze differences in mentees' communication behavior and networking behavior, we used nonparametric Kruskal–Wallis tests as the residuals in the ANOVAs were clearly not normally distributed and variances differed by format. There were significant differences between the formats for all communication and network variables (word count: $\chi^2(2) = 25.38$, $P < 0.001$; percentage of STEM words: $\chi^2(2) = 106.51$, $P < 0.001$; mentee contacts: $\chi^2(2) = 59.25$, $P < 0.001$; mentor contacts: $\chi^2(2) = 61.94$, $P < 0.001$; mentor STEM contacts: $\chi^2(2) = 92.30$, $P < 0.001$; local clustering: $\chi^2(2) = 107.24$, $P < 0.001$; and local STEM clustering: $\chi^2(2) = 100.43$, $P < 0.001$), except for the number of mentee STEM contacts ($\chi^2(2) = 0.78$, $P = 0.677$). The means and standard deviations of the variables, as well as the significance levels of the specific comparisons (Dunn–Bonferroni method), are reported in Table 2.

Mentees in the one-on-one mentoring format communicated significantly more on the platform than mentees in the hybrid format, who, in turn, communicated more than mentees in the group mentoring format. The STEM-related communication was highest in the hybrid mentoring format and did not differ between the one-on-one and group mentoring formats. Mentees in the one-on-one mentoring format showed the highest number of mentee contacts, whereas STEM-related mentee contacts did not differ between the formats. Both mentor contacts and STEM-related mentor contacts were highest in the hybrid format. Mentor contacts did not differ between the one-on-one

Table 2. Means and standard deviations of the communication and network variables in the different mentoring formats

	One-on-one mentoring		Group mentoring		Hybrid mentoring	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Word count	2594.47 ^a	5877.17	1869.31 ^b	4003.97	2137.68 ^c	12,260.62
Percentage STEM words	0.99 ^a	1.00	1.09 ^a	1.10	1.32 ^b	1.13
Mentee contacts	1.91 ^a	4.75	1.06 ^b	1.95	0.89 ^b	2.38
Mentee STEM contacts	0.30 ^a	1.16	0.27 ^a	0.74	0.24 ^a	0.60
Mentor contacts	1.04 ^a	1.56	1.09 ^a	1.30	1.19 ^b	1.11
Mentor STEM contacts	0.81 ^a	1.12	0.48 ^b	0.98	0.86 ^c	0.80
Local clustering	2.40 ^a	7.89	15.05 ^b	26.75	13.75 ^b	26.59
Local STEM clustering	0.36 ^a	4.00	3.61 ^b	14.96	5.35 ^b	18.35

NOTE. Means with different superscript letters (a, b, c) differ significantly ($P < 0.05$) from one another. The nonparametric Kruskal-Wallis test was used for the comparisons. The large SD of the word count in hybrid mentoring is mostly due to one extreme outlier.

mentoring and group mentoring formats. STEM-related mentor contacts were higher in group mentoring than in one-on-one mentoring (but lower than in hybrid mentoring). Local clustering, as well as local STEM clustering, was comparable in the hybrid and group mentoring formats; in both formats, there was substantially more local clustering and local STEM clustering than in the one-on-one mentoring format.

Aim 3

For Aim 3, we investigated the explanatory contribution made by mentees' communication behavior and networking behavior to interindividual differences in how mentees developed on the program outcomes (i.e., for STEM activities, elective intentions in STEM, and certainty about career plans). We will first reiterate for each format whether the variances of the growth trajectories (slopes) of STEM activities, elective intentions in STEM, and certainty about career plans were significant. We will then report the effects of the communication and networking variables on the growth trajectories of the outcomes.

On the basis of the previous research showing the importance of communication and networking,^{21,22,24,49,69,72} we used word count, percentage of STEM words, mentor STEM contacts, mentee STEM contacts, and local STEM clustering in the conditional models to predict

individual differences in the development of STEM activities, certainty about career plans, and elective intentions in STEM. We decided to report only the significant effects. Since we expected positive effects for all predictors, we used one-tailed P values to test our one-sided hypotheses.⁸⁷ In light of the large sample sizes, there is virtually no risk of overlooking practice-relevant effects by omitting nonsignificant standard effect sizes, as all of these were very small. Additionally, none of the effects we omitted showed P values close to the standard threshold of 0.05.

One-on-one mentoring. Interindividual differences between the growth trajectories were significant for all three outcomes (STEM activities: $Var = 158.66$, $P < 0.001$; elective intentions in STEM: $Var = 0.21$, $P = 0.002$; and certainty about career plans: $Var = 0.72$, $P < 0.001$).

STEM activities. None of our five predictors showed a significant relationship with the growth in STEM activities.

Elective intentions in STEM. None of our five predictors showed a significant relationship with the growth in elective intentions in STEM.

Certainty about career plans. We found a small positive effect of percentage of STEM words on the growth of certainty about career plans ($\beta = 0.08$, 95% CI (0.00–0.17), $P = 0.024$, one-tailed). Overall,

the predictors explained only 0.8% of the slope variance.

Group mentoring. Considering the rather small sample size and the previously discussed, clearly nonsignificant individual differences between the growth trajectories for all three outcomes (STEM activities: $Var = -88.65$, $P = 0.514$; elective intentions in STEM: $Var = 0.20$, $P = 0.309$; and certainty about career plans: $Var = 0.18$, $P = 0.660$), we decided not to perform the conditional analyses predicting growth trajectories of the outcomes.

Hybrid mentoring. Interindividual differences between the growth trajectories were significant for STEM activities ($Var = 107.06$, $P = 0.043$) and certainty about career plans ($Var = 0.58$, $P = 0.001$). Interindividual differences between the growth trajectories were not significant for elective intentions in STEM ($Var = 0.20$, $P = 0.116$). However, as the P value is comparably low, we decided not to treat significant slope variance as a prerequisite for further analyses as per current recommendations.⁸⁸

STEM activities. None of our five predictors showed a significant relationship with the growth in STEM activities.

Elective intentions in STEM. We found a positive effect of word count ($\beta = 0.27$, 95% CI (0.02–0.53), $P = 0.019$, one-tailed) and of percentage of STEM words ($\beta = 0.21$, 95% CI (–0.03 to 0.45), $P = 0.044$, one-tailed) on the growth of elective intentions in STEM. Overall, the predictors explained 7.7% of the slope variance.

Certainty about career plans. We found a positive effect of percentage of STEM words ($\beta = 0.20$, 95% CI (0.03–0.37), $P = 0.011$, one-tailed) and a small positive effect of mentor STEM contacts ($\beta = 0.14$, 95% CI (–0.01 to 0.28), $P = 0.035$, one-tailed) on the growth of certainty about career plans. Overall, the predictors explained 10% of the slope variance.

Discussion

The first aim of our study was to assess the general and relative effectiveness of three mentoring formats for increasing girls' STEM activities, elective intentions in STEM, and certainty about career plans. In all three mentoring formats—one-on-one mentoring, many-to-many group mentoring (in which three mentees and three mentors were combined into a mentoring community without indi-

vidual assignments of mentees to mentors), and hybrid mentoring (in which two mentoring dyads were combined into a mentoring community)—two of the three mentoring outcomes improved over the mentoring year (general effectiveness). The developmental trajectories of these mentoring outcomes did not differ between the three mentoring formats (relative effectiveness).

In all three mentoring formats, mentees' STEM activities and certainty about career plans increased over the mentoring year. Mentees' elective intentions in STEM did not change over the mentoring year in any of the three mentoring formats. Hence, our results appear to support the general effectiveness of the three mentoring formats for helping mentees to develop in the areas of STEM activities and certainty about career plans. As we did not have control groups for the three mentoring formats, a causal relation from mentoring format to the two outcomes cannot be identified on the basis of this study. However, two earlier studies of one-on-one mentoring in the same online-only program, which were longitudinal and included a waitlist control group,^{8,20} suggest that the relationships we observed are likely causal.

The increases we observed for mentees' STEM activities and certainty about career plans may, in the long run, help redress the underrepresentation of women in STEM. Research illustrates how increasing girls' STEM activities and certainty about career plans can increase the likelihood of later real-life choices about studying and working in STEM.^{64,65,67,68} For example, in a longitudinal study with secondary school students, it could be shown that students' STEM activities predicted their expectancies in and valuing of STEM, which, in turn, predicted the number of STEM courses they chose several years later.⁶⁵ Students' STEM activities were even more predictive for later elective decisions than their grades.⁶⁵ Other studies have illustrated a similar relationship between certainty about career plans and elective behaviors at the end of secondary school.⁶⁸ Looking only at the results of the current study, we cannot conclude that mentees' increases in STEM activities and certainty about career plans due to the online mentoring program will actually lead to real-life choices of STEM studies or professions. For this, follow-up studies would be needed. Still, our results can be interpreted as a first step in the right direction.

The missing effects for elective intentions in STEM in all three mentoring formats are unsatisfactory. The unexpected finding may be reflecting the very high levels of elective intentions in STEM that mentees reported at the first measurement point before participating in the program. Values between 4.76 and 4.89 and standard deviations between 0.82 and 0.88 on a six-point scale suggest a ceiling effect, which may be attributable to the scale design. Many of the scale items tapped relatively ephemeral choices, such as attending a lecture on a STEM topic. For future program rounds, scales should be considered that focus on assessing far-reaching elective intentions (e.g., university majors or year-long school electives). An improved scale might avoid ceiling effects and allow increases to be observed.

Our results complement and extend past research on the general effectiveness of the three online mentoring formats for supporting girls in STEM. Whereas the effectiveness of the one-on-one and hybrid formats of online mentoring has already been shown for this age group,^{8–11,20,23} our study is—to the best of our knowledge—the first to show that many-to-many group mentoring (without an individual assignment of one mentee to one mentor) can also be effective.

Our study is also the first to compare the effectiveness of the three mentoring formats in supporting girls in STEM (i.e., analyzing their relative effectiveness). Although different theoretical approaches^{35,52,53} suggest that the three formats might differ in their effectiveness for supporting girls in STEM, the only other study, so far, that has compared the effectiveness of mentoring formats in online mentoring for girls in STEM examined only one-on-one mentoring and a hybrid form that combined two mentoring dyads.²³ In that study, the hybrid format led to increases in mentees' elective intentions after 6 months of mentoring, whereas the one-on-one mentoring format did not. In our study, we did not find any differences in the effectiveness of the three formats. All three mentoring formats led to comparable increases in mentees' STEM activities and certainty about career plans. Mentees' elective intentions in STEM stayed comparably stable over time in all three formats. By investigating the relative effectiveness of the three mentoring formats, we sought to understand which of the formats was more effective for supporting girls in STEM.

However, neither our results nor those of the only relevant earlier study allow for a clear answer with regard to our three outcomes (i.e., STEM activities, elective intentions in STEM, and certainty about career plans). Before conclusions for practice can be drawn in this case, additional research is needed.

Our second study aim was to examine whether mentees' communication and networking behavior differed in the three mentoring formats. Our analyses show that mentees in the hybrid mentoring format communicated slightly more about STEM than mentees in the other two mentoring formats. Mentees' STEM-related contacts with mentors (i.e., mentors with whom they had communicated about STEM) were also most numerous in the hybrid mentoring format, followed by the group mentoring format and then the one-on-one mentoring format. The STEM-related networking between the mentees' communication partners was also higher in the hybrid mentoring format than in the one-on-one mentoring format, and equal to that in the group mentoring format.

Although mentees in the hybrid and many-to-many group mentoring formats communicated more about STEM and established more STEM-related network edges with mentors than did the mentees in the one-on-one mentoring format, the small effect sizes prevent us from drawing firm conclusions about which of the three formats best facilitates improvements in mentees' communication and networking behavior. The slight advantage we observed for the group mentoring and the hybrid mentoring formats in this area is worth additional investigation, because we know from earlier research that mentees who communicate more about program-relevant topics^{20,21} and network more^{23,24} tend to profit more from their mentoring programs. Additional studies that systematically compare mentoring formats are needed.

Even when mentoring formats are effective, they may differ in their effectiveness among the participating mentees. Therefore, our third study aim was to investigate the explanatory contributions made by communication behavior and networking behavior to interindividual differences in mentees' development on the mentoring outcomes (i.e., for STEM activities, elective intentions in STEM, and certainty about career plans) for each mentoring format separately. Unfortunately, we were not able to investigate the question for the many-to-many group

mentoring format. The number of study participants in that condition was too small, and the developmental trajectories of the three outcomes lacked a sufficient amount of variance.

For the one-on-one mentoring format, we found a small effect of mentees' STEM-related communication on the development of certainty about career plans. The more mentees communicated about STEM, the more their certainty about career plans increased. In the hybrid mentoring format, both STEM-related communication and the number of STEM-related mentor contacts were related to interindividual differences in mentees' increases in certainty about career plans. The more mentees communicated about STEM and the more STEM-related contacts they had with mentors, the more their certainty about career plans increased over the course of the mentoring year. In the hybrid mentoring format, interindividual differences in the development of mentees' elective intentions in STEM were also related to communication behavior and networking behavior. Although, on average, mentees' elective intentions did not increase over the mentoring year, the more mentees communicated and the more that communication focused STEM topics, the more their elective intentions increased over the course of the mentoring year in comparison to other mentees.

Our findings are in line with other studies describing how communication behavior and networking behavior help to explain interindividual differences in the effectiveness of mentoring programs.^{20,21,23,24} We found indications of this, both for the one-on-one and the hybrid mentoring formats. As the effects were small, future research is needed to replicate our findings. Of importance would be an initial examination of the influence of communication behavior and networking behavior on interindividual differences in the effectiveness of many-to-many group mentoring for girls in STEM.

More broadly, future research should consider additional facets of communication behavior and networking behavior. Besides the extent of communication and networking and their STEM-relatedness, other attributes likely also play a role. For example, research shows that mentees' subjective identification and connectedness with the peers and professionals they interact with influence the mentees' domain identification and commitment to pursue STEM careers.³⁸ Another relevant aspect

might be the emotional coloring of the communication and networking.^{89,90} Even if mentees communicate a lot about STEM, it makes a difference if this communication addresses ancillary problems (e.g., instructional climate in STEM classes in school, perceptions of STEM being unfeminine, and mentors' struggles with work–life balance) or interesting STEM topics (e.g., publications, projects, or new ideas for research).

Limitations

Although our study replicates the findings of earlier studies and broadens research on online-mentoring for girls in STEM, it also has various limitations. First, the effect sizes we observed were small. This applies for the significant increases we found in mentees' STEM activities and in their certainty about career plans—for all three mentoring formats. It also applies for most of the differences between mentoring formats in STEM-related communication behavior and networking behavior as well as for the explanatory contribution of communication behavior and networking behavior for interindividual differences in the development of certainty about career plans and elective intentions in STEM (within each format). The modest effect sizes are put into perspective to a certain extent in light of their context. Effect sizes are typically smaller in youth mentoring than in mentoring programs for adults,⁹¹ and the effect sizes we report are comparable to those reported for other youth mentoring programs.⁴¹ Nevertheless, the small effect sizes highlight the need for additional empirical work, including replications of our findings.

A second limitation of our study is the comparably small sample size of 231 mentees for the many-to-many group mentoring format and the fact that we only had data for one mentoring year for this format. Although samples of 200 or more subjects are viewed as sufficiently large for the sorts of analyses we conducted,⁹² the smaller sample for the many-to-many group mentoring format, nevertheless, limits the conclusions we can draw for this format. Although our results give first indications about the effectiveness of many-to-many group mentoring formats in online mentoring for girls in STEM, in future studies, comparable many-to-many mentoring formats should be surveyed to replicate our findings and to better understand

whether and under which conditions the format can effect positive mentoring outcomes.

A third limitation of our study is that the three mentoring formats were not implemented simultaneously but consecutively. The mentoring formats' sequential implementation could lead to a history effect. In other words, differences in mentoring outcomes, as well as communication behavior and networking behavior, might be caused by societal changes over the surveyed mentoring years, not by format changes. Two such long-term changes seem especially relevant. First, changes in participation rates of girls and women in STEM or changes in stereotypes about STEM being unfeminine might have influenced the outcomes of the mentoring program. Second, the evolution of personal communication technology might have influenced the outcomes. While we stress the importance of noting these limitations when planning future research, we also see reasons why such a history effect seems uncertain or may only have a limited effect in the case of our study. We briefly note these reasons.

Regarding the possibility of historical changes in the participation rates of girls in women in STEM and in gender stereotypes about STEM, our findings do not support such a connection. The girls' responses about their STEM activities, elective intentions in STEM, and certainty about career plans given at the beginning of the individual mentoring years were comparable across all 9 mentoring years surveyed. Should there be a history effect in the area of STEM and gender, one would have expected to find systematically changing starting values for these variables between 2009 and 2017, which we did not. This finding is in keeping with the fact that the participation rates of women in STEM in Germany have only increased slightly over the last decade, both in education and the labor force.^{1,2,77}

A history effect seems conceptually possible with respect to evolving personal communication technology (e.g., the prevalence of smartphones). With the ever-deeper integration of personal electronics into everyday life, it seems likely that mentees may have become more and more accustomed to social media and using communication tools, such as chat, forums, and emails between 2009 and 2017. Increased communication technology penetration might, for example, lead to increases in

overall levels of communication and networking on the platform over time. However, our data do not support such an explanation. Overall levels of networking decreased during the phase of the hybrid mentoring format (2013–2017) in comparison to the phase of many-to-many group mentoring (2012); and the trend was analogous for mentees' overall word count. Finally, even if the spread of personal communication technology were to be affecting changes in overall levels of online communication, such an effect would not explain why the proportion of *STEM-related* communication and STEM-related networking increased over time. Research suggests that successful mentoring in STEM depends mainly on the STEM-relatedness of communication and networking.^{20,23} Nonetheless, future research is needed to replicate our findings by implementing the different formats within the same program and during the same period of time. Independent of this limitation, our study is the first to compare different online mentoring formats within the same program and, therefore, makes an important contribution to the research literature.

Finally, our study is limited by the lack of control groups for each of the mentoring formats we examined. Particularly desirable would be waitlist control groups consisting of girls who also registered for the same format of the online mentoring program but were randomly selected to participate 1 year later. Only such control groups ensure that increases in STEM activities and certainty about career plans can be attributed to the mentoring format rather than to an artifact of the special group of girls who chose to register for such programs.²⁰ Our lack of waitlist control groups for the different formats reflected financial and practical restraints faced by the mentoring program we examined. However, this limitation is somewhat less problematic for the current study in light of earlier related research. The effectiveness of the program we investigated was previously demonstrated for the one-on-one mentoring format via a comparison with a waitlist control group.²⁰ That research showed more positive developments of mentoring outcomes for mentees than for girls in the waitlist control group. As we showed that the three formats led to comparable outcomes (relative effectiveness), the assumption appears reasonable that increases in mentees' STEM activities and certainty about career plans can be attributed

to the mentoring they had received. Nevertheless, future research should revisit the comparisons made in this study with additional waitlist control groups.

Closing remarks

Our study replicates existing research and provides novel findings on the effectiveness of online mentoring in the context of promoting girls in STEM. Although our findings do not permit us to make firm recommendations for the practice of online mentoring, our results suggest that traditional one-on-one mentoring, many-to-many group mentoring, and a hybrid form of mentoring (combining the two formats) can be effective. This finding allows those planning and implementing online mentoring for girls in STEM to be somewhat flexible in the decisions they make about mentoring formats. The study findings also suggest that the hybrid mentoring format and, to a lesser degree, the many-to-many group mentoring format facilitate mentees' STEM-related communication and networking on the platform more effectively than the one-on-one mentoring format. Such group mentoring formats may, in the long run, help programs to achieve more desirable developments on chosen mentoring outcomes.^{21,22,37,38,69} However, a more differentiated understanding of the implications of these initial findings for the practice of mentoring requires additional studies, for which we have indicated some possibilities.

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Competing interests

The authors declare no competing interests.

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