ADVANCED LEARNING

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ADVANCED LEARNING

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EDITORIAL
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Editorial: Advanced Learning

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Keywords: deliberate practice, advanced learners, developmental trajectory, learning resources, giftedness

Editorial on the Research Topic

Advanced Learning

This issue on advanced learning focuses on the educational and developmental needs of advanced learners as they develop towards excellence. We speculated that those needs could be observed in at least three ways. The first is that the advanced learner requires educational interventions that are more closely aligned to the "deliberate practice" approach delineated by Ericsson et al. (1993). Ericsson et al. (1993) identified that the number of hours of deliberate practice differentiated among the performance levels of musicians. Deliberate practice can be described as individualised instruction whereby a teacher or coach identifies the goals and activities that need to be adopted by an individual during practice to improve their performance.

A second assumption is that advanced learners do not attain high levels of performance in the absence of environmental factors but the factors that support the talent developmental trajectory of advanced learners will not be the same as those that support them at earlier stages. The expertise reversal effect, for example, suggests that the instructional activities designed for novices may have a detrimental effect on more advanced learners Kalyuga (2007).

The third premise is the need for more tailored and well-designed learning resources to support talent development. Such learning resources include highly-specialised learning materials and curricula, expert teachers and coaches, mentors, and so on, which are purposefully designed to meet the individual's specific needs at a specific point in the talent development process. Again, this echoes the deliberate practice approach described earlier.

Ericsson's work on deliberate practice in expertise development is a key consideration, then, in this issue on advanced learning. Responding to critiques that questioned the extent of the contribution of deliberate practice to performance [see Macnamara et al. (2014)], in their paper Ericsson and Harwell carefully set out three criteria to determine whether practice regimens qualify as deliberate practice. The resulting analysis confirms the earlier work of Ericsson et al. (1993).

Gilar-Corbi et al. examined a range of non-cognitive variables to determine their impact on the academic outcomes of secondary students. Their comparison of underachieving and achieving gifted students revealed that the underachieving group had lower scores for learning strategies, goal orientations, self-concept, attitudes towards teachers, and perceptions of parent involvement in school. While these results underline the importance of particular personal and environmental resources in academic performance, what may be even more important is how gifted students may be assisted in learning to use the resources available to them more effectively. This does imply an approach that delivers the right supports to students at the right time for their developmental trajectory.

Barbier et al. compare achieving and underachieving gifted students. Their paper focuses on the lived experiences of the six participants who share intellectual gifted potential but differ in their achievement trajectories. The lived experience approach examines the individual within their environmental contexts. The authors demonstrate the role of supportive environments on the individuals' motivations, task engagement, and academic achievement.

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Similar observation of the ways in which environmental supports or resources are reflected in individual psychosocial behaviours are evident in the contribution from Subotnik et al. These authors highlight the bi-directionality of the individual and environmental effects. They raise questions about how domains differ in terms of the nature of the interaction influence. It is important to note that talent development is not universal; domains play a part and thus, talent development in particular domains will require specific types of environment in which to flourish along with specific responses from individuals to those environmental influences.

Domain-specificity is also at the heart of the Reutlinger et al. study. In seeking to understand how individuals attain excellence in a specific domain, the authors examined the contribution of learning resources to talent development, and particularly whether domain-specificity of learning resources could be observed across two separate domains of school learning and learning a musical instrument. The study supported the domain-specificity of the resources, thereby reinforcing the conclusions of both the Ericsson and Harwell and Subotnik et al. papers that the talent development process requires specific attention that is unique to the individual's trajectory through a particular domain.

Zhou et al. questioned whether the filial piety correlates with the academic achievement of secondary students in China. Further, they investigated whether a similar pattern could be observed in other global settings. As hypothesised by the researchers, reciprocal filial piety was correlated with academic outcomes and with the need for autonomy. Their modelling also suggested that the association of the filial piety with academic achievement was via the need for autonomy. Analysis of global datasets, such as PISA, showed some evidence of similar patterns, thereby providing some support to the psychological construct's broader global influence. While additional research would be needed to further test these relationships, the findings do support other papers in this issue which speak to the critical role of familial learning resources in achievement outcomes.

While many of the papers in this issue focus on older children or adults, Howard and Vasseleu were interested in the early years, a critical period for the establishment of children's developmental trajectories. In this longitudinal study, the authors explored whether advanced preschoolers differed from their non-advanced peers in executive function and self-regulation. Their results confirmed that stronger cognitive development (reflected in combined executive functions and cognitive self-regulation) along with age and socioeconomic context consistently predicted stronger learning performances in the preschoolers. Interestingly, though, the advanced learners attained lower behavioural self-regulation ratings, which the authors speculate may promote rather than constrain learning.

The importance of mentors in supporting the development of advanced learners has been well-established but has predominantly focused on the mentor-mentee relationship. What is missing from these analyses is the role that peers play in the outcomes arising from mentoring. In their study of female secondary school students participating in an online STEM mentoring program, Hopp et al. addressed this gap in the literature. The longitudinal study showed that the measured outcomes were indeed influenced by the mentees' peers in the program but this effect was moderated by age, whereby younger mentees became more similar and older mentees became more dissimilar. There was also some evidence of the size of the peer groups bearing some influence for the younger mentees. This interesting research, in demonstrating age-related differences, reinforces the theme demonstrated elsewhere in this issue that the development of advanced learners requires the delivery of the right educational experiences at the right time for the individual in their trajectory towards outstanding achievement.

AUTHOR CONTRIBUTIONS

WV drafted the editorial. HS contributed to the design of the issue and to the writing of the editorial. AZ conceptualised the design of the issue and reviewed the draft of the editorial. All authors contributed to the article and approved the submitted version.

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ORIGINAL RESEARCH
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Factors Determining the Behavioral Intention to Use Mobile Learning: An Application and Extension of the UTAUT Model

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This study developed and empirically tested a model to predict the factors affecting students' behavioral intentions toward using mobile learning (m-learning). This study explored the behavioral intention to use m-learning from the perspective of consumers by applying the extended unified theory of acceptance and use of technology (UTAUT) model with the addition of perceived enjoyment, mobile self-efficacy, satisfaction, trust, and perceived risk moderators. A cross-sectional study was conducted by employing a research model based on multiple technology acceptance theories. Data were derived from an online survey with 1,562 respondents and analyzed using structural equation modeling. Partial least squares (PLS) regression was used for model and hypothesis testing. The results revealed that (1) behavioral intention was significantly and positively influenced by satisfaction, trust, performance expectancy, and effort expectancy; (2) perceived enjoyment, performance expectancy, and effort expectancy had positive associations with behavioral intention; (3) mobile self-efficacy had a significantly positive effect on perceived enjoyment; and (4) perceived risk had a significantly negative moderating effect on the relationship between performance expectancy and behavioral intention. Our findings correspond with the UTAUT model and provide a practical reference for educational institutions and decision-makers involved in designing m-learning for implementation in universities.

Keywords: mobile learning, mobile self-efficacy, unified theory of acceptance and use of technology model, trust, perceived enjoyment, perceived risk

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INTRODUCTION

With the recent rapid advancement in mobile telecommunication technologies, mobile phone applications have changed not only how we use mobile phones but also our lives. People now through new methods by using mobile gadgets and technologies. Thus, mobile devices are a crucial tool for mobile health, banking, and mobile learning (m-learning) (Alalwan et al., 2017; Briz-Ponce et al., 2017; Hoque and Sorwar, 2017; Nikou and Economides, 2017; Crompton and Burke, 2018). M-learning is a tool with considerable potential that provides new possibilities for education and learning assessment (Nikou and Economides, 2017). The United Nations Educational, Scientific and Cultural Organization (UNESCO) indicated the potential of m-learning to enhance learning quality and students' test results. In addition, UNESCO has suggested that governments should

adopt new technologies to secure equal access to mobile connectivity and enable students to gain further learning possibilities (UNESCO, 2009). M-learning is a critical component of higher education, and thus its acceptance and adoption receives growing interest. However, recent studies (Kim et al., 2017; Hamidi and Chavoshi, 2018) have indicated that although many universities have extended their online learning platforms to mobile services, students' interest and usage of m-learning is not as high as expected. Thus, investigating the factors affecting university students' acceptance of m-learning and their intentions to use it in a comprehensive and integrated manner is critical (Nikou and Economides, 2017; Briz-Ponce et al., 2017). Therefore, this study examined the behavioral intentions of university students to use m-learning.

Effective implementation of any information technology (IT) or information system (IS) depends on user acceptance (Davis, 1989). In recent decades in the domains of psychology, ISs, and sociology, numerous theoretical models have been developed to predict and explain user acceptance of IT or ISs. One of the most widely cited frameworks in the field of IT and ISs is the technology acceptance model (TAM) (Chauhan and Jaiswal, 2016; Cimperman et al., 2016; Šumak and Šorgo, 2016; Šumak et al., 2017). However, some scholars (Sánchez-Prieto et al., 2016; Šumak et al., 2017; Tsai et al., 2018) have contended that the TAM has several disadvantages, including (1) not providing adequate insight into individuals' perspectives of novel systems; (2) neglecting its indicators and directly investigating the external variables of perceived ease of use (PEOU) and perceived usefulness (PU); and (3) ignoring the relationship between usage attitude and usage intention. In their search for a more complete IT acceptance model and to address the weaknesses of the TAM, Venkatesh et al. (2003) integrated core elements from eight models and prominent theories (including the theory of reasoned action [TRA], innovation diffusion theory [IDT], the theory of planned behavior [TPB], the TAM; the combined TAM-TPB, the motivational model (MM), the model of PC utilization [MPCU], and social cognitive theory [SCT]) to predict or explaining new technology adoption, acceptance, and usage, and proposed a unified model called the unified theory of acceptance and use of technology (UTAUT) model.

Since its introduction, the UTAUT model has been applied and tested extensively for predicting system usage and making technology-adoption- and technology-usage-related decisions in various fields such as interactive whiteboards (Šumak and Šorgo, 2016; Šumak et al., 2017), near-field communication technology (Khalilzadeh et al., 2017), mobile health (Hoque and Sorwar, 2017), home telehealth services (Cimperman et al., 2016), and acceptance of Enterprise Resource Planning (ERP) software (Chauhan and Jaiswal, 2016). Applied research regarding the UTAUT model has been extensive. This model provides a framework that not only explains acceptance of IT and ISs but also elucidates the actual use of such technologies and systems. Because of its capability to integrate different the TAMs, the UTAUT model contributes substantially to the exploration of technology acceptance and usage (Venkatesh et al., 2003). Therefore, this study used the UTAUT model as the theoretical basis to evaluate the influences of technology-related factors on m-learning adoption.

Although the UTAUT model has been widely adopted, doubts exist over its capability to explain individuals' technology acceptance. Thus, the original UTAUT model has been extended. Many researchers (Martins et al., 2014; Maillet et al., 2015; Cimperman et al., 2016; Kabra et al., 2017; Khalilzadeh et al., 2017) have suggested that increasing the number of external variables can enhance this model's ability to predict the acceptance of IT. Several variables have been recommended to complement the original UTAUT model (e.g., self-efficacy, trust, habits, satisfaction, and perceived risk). For example, Kabra et al. (2017) incorporated personal innovation specific to IT and trust into the UTAUT model to evaluate the factors that influence users' behavioral intentions to use IT. Khalilzadeh et al. (2017) included self-efficacy, risk, trust, security, and attitude to evaluate the factors that influence users' behavioral intentions to make mobile payments. According to previous study on mobile technologies (Alalwan et al., 2017; Khalilzadeh et al., 2017), trust is a crucial factor determining users' behavioral intentions to adopt technology. Chang et al. (2017) posited that perceived enjoyment is critical in explaining e-learning adoption. As mentioned, the present study proposed an extension of the UTAUT model by adding variables (mobile self-efficacy, perceived enjoyment, satisfaction, perceived risk, and trust) to predict adoption of m-learning.

The UTAUT model was adopted and extended by incorporating the constructs of mobile self-efficacy and perceived enjoyment in addition to security-related constructs (i.e., satisfaction, trust, and perceived risk) to investigate university students' behavioral intentions toward using m-learning in higher education. The UTAUT model was modified by incorporating new constructs such as perceived enjoyment, mobile self-efficacy, satisfaction, trust, and perceived risk. The modified model was then empirically tested. The four primary objectives of this study were (1) to investigate the factors influencing behavioral intention to use m-learning in education; (2) to develop an extended UTAUT model incorporating perceived enjoyment, mobile self-efficacy, trust, satisfaction, and perceived risk for m-learning; (3) to examine whether effort expectancy, performance expectancy, and perceived risk moderate and predict behavioral intention to use m-learning; and (4) to assess the resultant model empirically. To achieve the aforementioned objectives, the following research questions were formulated. (1) What factors determine students' behavioral intentions to use m-learning for educational purposes? (2) Do perceived enjoyment, mobile self-efficacy, trust, and satisfaction affect the UTAUT model in relation to m-learning? (3) Does mobile self-efficacy influence perceived enjoyment in m-learning? (4) How does perceived risk moderate the effects of effort expectancy and performance expectancy on behavioral intention to use m-learning? This research is expected to contribute to the literature by (1) identifying satisfaction, trust, and perceived enjoyment as antecedents of m-learning usage; (2) advancing the theoretical understanding of behavioral intention among university students with respect to m-learning; (3) providing empirical evidence of the effects of external

factors on effort expectancy and performance expectancy, which lead to usage-related satisfaction and behavioral intention; (4) proving that perceived risk moderates the effects of effort and performance expectancy; (5) providing a reference for teachers and educational institutions for deciding future development directions and approaches related to the implementation of m-learning.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

The hypotheses developed in the current study were based on a robust foundation derived from contemporary studies. To achieve the research objectives, four external variables (mobile self-efficacy, perceived enjoyment, satisfaction, and trust) were used as external variables for the proposed UTAUT model. This study employed and empirically tested the proposed UTAUT model in the context of m-learning by recruiting university students in central Taiwan and determining the effects of the four aforementioned external variables on students' effort expectancy, performance expectancy, and satisfaction toward m-learning. This study determined how students and their behavioral intention toward m-learning can be influenced by their attitude. Perceived risk was considered to have had a moderating effect on the interrelationships between effort expectancy, performance expectancy, and behavioral intention.

Definition of M-Learning

The rapid advancement of mobile and wireless technologies has resulted in increasing use of mobile devices in education and has changed approaches to learning. Additionally, new terms such as e-learning and m-learning have been coined. Over the preceding 10 years, use of IT has expanded from programmed instruction, through computer-assisted instruction, to Internet-connected e-learning, and further to m-learning. In particular, m-learning for educational use has become increasingly common, and thus has received increasing attention from researchers and educators (Briz-Ponce et al., 2017; Kim et al., 2017; Nikou and Economides, 2017; Crompton and Burke, 2018; Hamidi and Chavoshi, 2018; Hamidi and Jahanshaheefard, 2019). M-learning is a critical component of higher education that enables students to learn anytime and anywhere. However, although m-learning is a pertinent topic of discussion, a single definition has not been established. Hamidi and Chavoshi (2018) argued that alongside the Internet and the development of technology, m-learning offers an online learning environment through which students can learn and interact. Martin and Ertzberger (2013) defined m-learning as a method of learning that is enabled when learners have access to information anytime and anywhere through mobile technologies, allowing them to participate in authentic activities while learning. Yousafzai et al. (2016) defined m-learning as a learning process where learners are not restrained by fixed locations and can benefit from access to learning materials through mobile devices. Similar to other teaching methods, m-learning has many advantages from the perspective of users, such as a substantial amount of learning resources, rapid access to information, two-way interaction, and removal of time- and location-related restrictions (Briz-Ponce et al., 2017; Kim et al., 2017; Tang and Hew, 2017; Crompton and Burke, 2018; Hamidi and Chavoshi, 2018; Hamidi and Jahanshaheefard, 2019). In this study, we defined m-learning as a learning process conducted across various contexts (location, time, and other environmental factors) where learners can benefit from access to learning materials through smart mobile devices such as smartphones and tablet computers.

UTAUT

In the search for a more comprehensive IT acceptance model, Venkatesh et al. (2003) reviewed related studies and conducted an empirical study where they synthesized several elements of the eight behavioral intention models used in previous technology acceptance contexts. These models include (1) the TRA (Sheppard et al., 1988; Davis et al., 1989); (2) the TAM (Davis, 1989; Davis et al., 1989; Venkatesh and Davis, 2000); (3) the TPB (Ajzen, 1991; Taylor and Todd, 1995); (4) the combined TAM-TPB (Taylor and Todd, 1995); (5) the MPCU (Thompson et al., 1991); (6) the MM (Vallerand, 1997); (7) SCT (Bandura, 1986; Compeau and Higgins, 1995); and (8) IDT (Rogers, 2003). Therefore, the researchers applied the UTAUT model to unify the existing theories regarding how users accept technology (Venkatesh and Morris, 2000; Venkatesh et al., 2003).

Based on a systematic analysis and comparison of the aforementioned models, Venkatesh et al. (2003) proposed an integrated model, namely the UTAUT model, which can explain 70% of the variance in user intention. The results of that empirical study demonstrated that the UTAUT model is the most effective model for analyzing technology acceptance. The UTAUT model consists of six main constructs, namely performance expectancy ("PE" hereafter), effort expectancy ("EE" hereafter), social influence (SI), facilitating conditions (FC), behavioral intention ("BI" hereafter) to use the system, and usage behavior (see **Figure 1**). The UTAUT model contains four essential determining components and four moderators. According to the model, the four determining components of BI and usage behavior are PE, EE, SI, and FC (Venkatesh et al., 2003). Gender, age, experience, and willingness to use are the moderators that affect usage of technology (see **Figure 1**).

Effort expectancy has been introduced in the UTAUT model, and is a crucial predictor of technology acceptance. According to Venkatesh et al. (2003), EE is "the degree of ease associated with the use of the system." According to Cimperman et al. (2016), the antecedents of EE are ease of use, complexity, and PEOU. PE has also been introduced in the UTAUT model, and has been defined as "the degree to which an individual believes that the system helps to improve job performance." BI has been defined as "the degree to which a person has formulated conscious plans regarding whether to perform a specified future behavior." In the context of the present study, EE represents university students' beliefs regarding the ease of use of m-learning. PE denotes students' beliefs regarding whether use of m-learning will enhance their learning performance. Venkatesh et al. (2003) revealed that PE is the strongest determinant of a user's BI to adopt a technology.

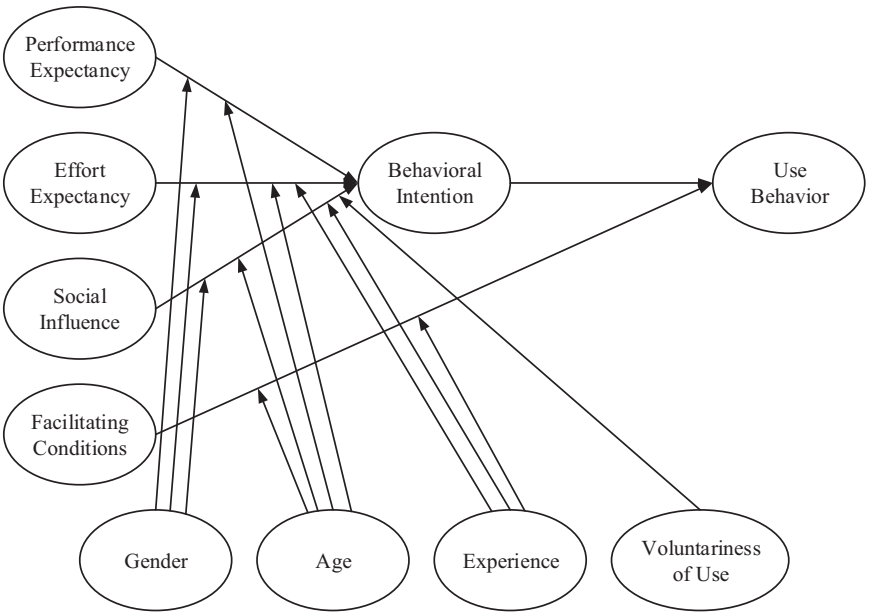

FIGURE 1 | The unified theory of acceptance and use of technology (UTAUT) model.

According to one study, (Venkatesh et al., 2003; Šumak and Šorgo, 2016; Hoque and Sorwar, 2017; Khalilzadeh et al., 2017; Šumak et al., 2017) PE and EE are direct determinants of BI. The present study hypothesized that PE and EE can significantly influence students' BIs toward acceptance and adoption of m-learning. The following hypotheses were proposed.

Hypothesis 1: EE has a significant influence on the BIs of university students to use m-learning.

Hypothesis 2: PE has a significant influence on the BIs of university students to use m-learning.

Effects of Satisfaction and Trust

Satisfaction and trust are critical factors for predicting individuals' BIs toward adopting ISs or IT (Koufaris and Hampton-Sosa, 2004; DeLone and McLean, 2016; Kabra et al., 2017). From the perspective of the IS success model, user satisfaction can significantly influence individuals' BI to use a particular system (DeLone and McLean, 2016). DeLone and McLean (2016) defined satisfaction as "users' level of satisfaction with reports, web sites, and support services." Maillet et al. (2015) indicated that EE and PE had significant effects on satisfaction. In addition, Shiau and Luo (2013) suggested that perceived enjoyment had a significant influence on satisfaction. Therefore, we defined that students' satisfaction with m-learning may be influenced by not only cognitive appraisals (e.g., EE and PE) but also emotions experience (e.g., perceived enjoyment). In addition, this study argued that students' satisfaction levels can significantly influence their BIs to use m-learning.

Arpaci (2016) defined trust as "students' perceptions about the reliability and trustworthiness of the system," whereas Alalwan et al. (2017) defined it as the "accumulation of trust beliefs: integrity, benevolence, and ability that relate with the bank and mobile-banking channel." According to previous studies (Arpaci, 2016; Alalwan et al., 2017), students' trust levels were operationalized as their perceptions of beliefs concerning reliability and trust (i.e., integrity, benevolence, and ability) in relation to m-learning. Notably, research findings regarding the effect of trust on BI remain inconclusive. Although most related studies have identified positive effects of trust on BI, some have found no such relationship (Alalwan et al., 2017; Kabra et al., 2017; Khalilzadeh et al., 2017). For example, Alalwan et al. (2017) confirmed that trust is important in determining users' likelihood to adopt mobile technologies. The researchers revealed that trust had a considerable effect on students' BIs toward using m-learning. However, Kabra et al. (2017) found no significant association between trust and BI. We proposed that students' trust levels positively influence their BIs to use m-learning. Based on this discussion, the following hypotheses were proposed.

Hypothesis 3: Satisfaction has a significant influence on the BIs of university students to use m-learning.

Hypothesis 4: Trust has a significant influence on the BIs of university students to use m-learning.

Hypothesis 5: EE has a significant influence on satisfaction with m-learning.

Hypothesis 6: PE has a significant influence on satisfaction with m-learning.

Hypothesis 7: Perceived enjoyment has a significant influence on satisfaction with m-learning.

Effect of Perceived Enjoyment

Perceived enjoyment is a fundamental intrinsic motivation that specifies the extent to which fun can be derived from using IT or an IS. Regarding ISs, Park et al. (2012) defined perceived enjoyment as "the extent to which the activity of using a specific system is perceived to be enjoyable in its own right, aside from any performance consequences resulting from system use." Accordingly, in the present study, we explored the positive and negative effects of perceived enjoyment on m-learning. The effect of perceived enjoyment on system use was confirmed in a previous study (Sánchez-Prieto et al., 2016; Chang et al., 2017; Tsai et al., 2018), and perceived enjoyment is the most commonly used external factor in the TAM. Perceived enjoyment is a key external factor that significantly influences individuals' PU, PEOU, and usage intentions toward an IS. However, few studies have examined whether perceived enjoyment is an influential external factor in the UTAUT model. In the UTAUT model, PE and EE are the two most relevant predictors derived from PU and PEOU, which were introduced in the original TAM model (Cimperman et al., 2016). Accordingly, we maintained that perceived enjoyment regarding use of m-learning has significantly positive effects on PE and EE. Based on this discussion, the following hypotheses were proposed.

Hypothesis 8: Perceived enjoyment has a significant influence on the EE of m-learning.

Hypothesis 9: Perceived enjoyment has a significant influence on the PE of m-learning.

Effect of Mobile Self-Efficacy

According to SCT proposed by Bandura (1986), self-efficacy refers to people's assessments of their effectiveness or ability to perform a specific task well; it is related not to the skills of an individual but rather to how he or she utilizes these skills (Bandura, 1986). In this context, self-efficacy is an individual's personal belief that he or she possesses the aptitude and skills to succeed when engaging in an m-technology-related task (Ozturk et al., 2016). Nikou and Economides (2017) defined mobile self-efficacy as an individual's perceptions of his or her ability to use mobile devices to accomplish particular tasks (e.g., browsing the Internet). Mobile self-efficacy has been identified as playing a significant role in the adoption of mobile devices to supplement education. To our knowledge, no study has investigated the possible effects of mobile self-efficacy on perceived enjoyment, and theoretical foundations for such a study have not been established. Based on the findings of aforementioned studies, we hypothesized that students' self-efficacy in using mobile devices can directly affect their perceived enjoyment of m-learning. Therefore, this study proposed the following hypothesis.

Hypothesis 10: Mobile self-efficacy has a significant influence on the perceived enjoyment of m-learning.

Moderating Effect of Perceived Risk

Because this study was investigating the Internet and mobile devices, risk factors in the process of m-learning had to be measured. Users often worry about risks such as privacy problems, system errors, losing passwords, incompatibility of mobile operating systems and security software, and low system quality. Hanafizadeh et al. (2014) stated that risk factors are crucial in mobile services, and the higher the risk of using a new technology, the lower is willingness to use. Alalwan et al. (2018) argued that the likelihood of a customer experiencing a finance- or privacy-related loss during the process in pursuit of a favored consequences of using Internet banking. Featherman and Pavlou (2003) defined perceived risk as the "potential for loss in the pursuit of a desired outcome of using an e-service." In the present study, we defined perceived risk as the likelihood of a student suffering a loss in the pursuit of m-learning.

To our knowledge, most related studies have examined perceived risk as an external factor influencing the external variables of the UTAUT model (Martins et al., 2014; Alalwan et al., 2018). Alalwan et al. (2018) argued that perceived risk considerably hinders BI. However, no study has examined whether perceived risk acts as moderating factor for any of the UTAUT model's moderator variables. The present study tested the UTAUT model in relation to m-leaning by adding the factor of perceived risk to the model. We hypothesized that as a moderating factor, perceived risk can influence university students' EE and PE of m-leaning. In other words, perceived risk moderates the relationships between the independent variables (i.e., EE and PE) and the dependent or outcome variable (i.e., BI). Accordingly, we posited that the relationships between these variables are weakened when perceived risk is considered. To examine this idea in detail, the following moderating effects were hypothesized.

M1: The relationship between EE and BI is moderated by perceived risk ("PR" hereafter).

M2: The relationship between PE and BI is moderated by PR.

In this study, the UTAUT model was chosen as a basis for investigating university students' perceptions of m-learning. **Figure 2** presents a research model that explains the use of BI for m-learning and the hypothesized relationships between variables. The external UTAUT model variables are grouped based on user factors (mobile self-efficacy, perceived enjoyment, satisfaction, and trust). To analyze the differences in causal relationships among UTAUT factors, we extended the base model by including PR as a variable to assume a moderating role within the model (**Figure 2**). Eight predictors formed an extended UTAUT model for predicting BI. **Figure 2** presents the conceptual model. The relationships among the constructs (arrows) represent the research hypotheses.

RESEARCH METHODOLOGY

Instrumentation and Data Collection Tools

A questionnaire was designed and divided into two sections. In the first section, 31 items were used to measure the eight constructs presented in the research model (**Figure 2**). These eight constructs were categorized as (1) exogenous variables

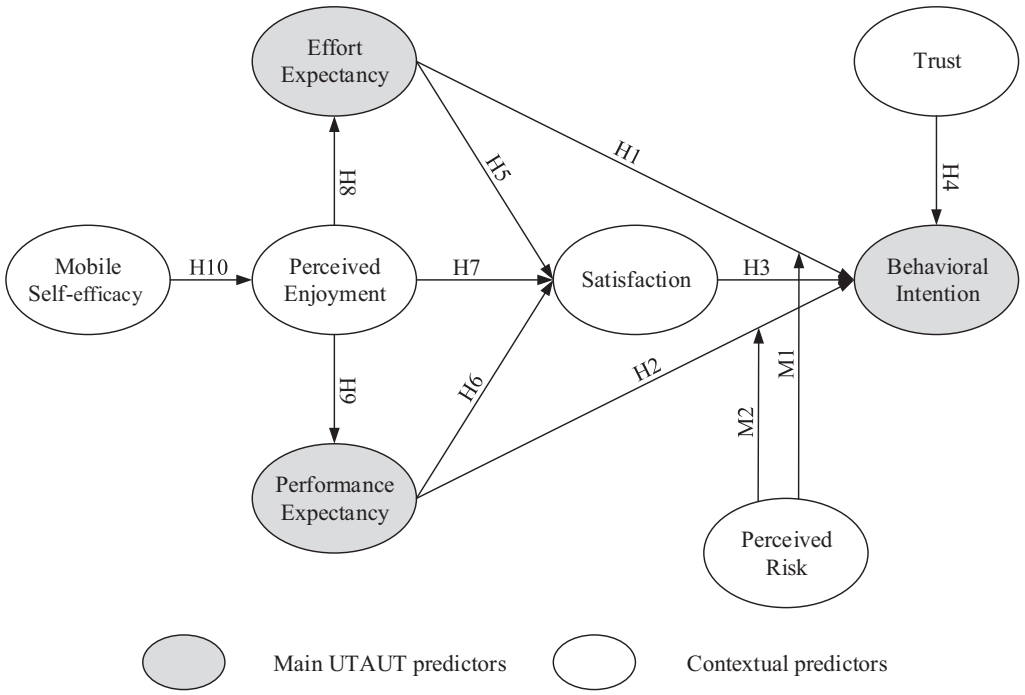

FIGURE 2 | Conceptualized extended UTAUT model for measuring university/college students' acceptance of mobile learning.

(mobile self-efficacy and trust), (2) endogenous variables (PE, EE, perceived enjoyment, satisfaction, and BI), and (3) a moderator variable (PR). Each construct is measured by multiple items. To quantify the constructs, a 5-point Likert scale was adopted to score questionnaire responses. The Likert scale consisted of five answer options ranging from "*strongly disagree*" (mapped to number 1) to "*strongly agree*" (mapped to number 5). The second section contained demographic information presented on a nominal scale. The questionnaire collected basic information about respondent characteristics, including age, gender, school, and grade.

The instrument (i.e., EE, PE, BI, mobile self-efficacy, perceived enjoyment, satisfaction, trust, and PR) was developed after a thorough review of studies related to the UTAUT model. Following MacKenzie et al. (2011) and the development procedures suggested by DeVellis (2003), standard psychometric scales were developed. The main constructs of the UTAUT model (i.e., EE, PE, and BI) were adopted from measurement constructs developed in related studies (Venkatesh et al., 2003; Cimperman et al., 2016; Šumak and Šorgo, 2016; Hoque and Sorwar, 2017; Khalilzadeh et al., 2017; Šumak et al., 2017). The EE measure contained five items, PE had four items, and BI had three items. Students' mobile self-efficacy in m-learning was measured based on three items from related studies (Bandura, 1986; Ozturk et al., 2016; Nikou and Economides, 2017); perceived enjoyment contained three items (Venkatesh, 2000; Park et al., 2012; Chang et al., 2017; Tsai et al., 2018), satisfaction had five items (Maillet et al., 2015; DeLone and McLean, 2016), trust contained five items (Arpaci, 2016; Alalwan et al., 2017; Kabra et al., 2017; Khalilzadeh et al., 2017) and PR had three items (Hanafizadeh et al., 2014; Martins et al., 2014; Alalwan et al., 2018). Details on the questionnaire used are shown in **Appendix Table A1**. To improve the questionnaire's validity, we conducted a pilot study prior to the actual test. The main objective of the pilot study was to empirically validate the reliability of the questionnaire by checking the accuracy and precision of all measurement items (Hair et al., 2010). For each construct, reliability was checked based on Cronbach's alpha, for which the threshold was set to 0.7 (Hair et al., 2010). In the pilot test, we received 122 complete responses from students at two universities in Taichung, Taiwan. The reliability scores, which were based on the Cronbach's alpha scores, ranged from 0.758 for PR to 0.898 for satisfaction. The results indicated that the Cronbach's alpha values for all variables exceeded 0.7. After the appropriate level of reliability had been confirmed for all measurement items, the final questionnaire proved reliable and usable.

Participants

Empirical data were collected using a cross-sectional survey. We recruited 2,000 students from ten universities (including general universities and universities of science and technology) in Taiwan. Two hundred students were randomly selected from each sample university. All participating students had experience of using mobile devices for personal learning. To maximize the survey response rate, we recruited a contact person at each selected school to manage the questionnaire distribution process. The study ethics procedures were executed according to the 1964 Helsinki declaration and its later amendments or comparable ethical standards and the ethical

norms of the Taiwan Ministry of Science and Technology do not require ethical external approval. This exemption was because the data was anonymous and there is no way for readers to be able to identify the participants. There are no name lists that correspond to the respondents of questionnaire and the names of the participating universities were not mentioned. All subjects were informed about the research and all participants include in the study provided informed consent. All respondents were volunteers and were assured that their responses would remain anonymous, their confidentiality would be maintained, and their answers would be used only for research purposes. It took the participants 15–20 min to complete the questionnaire. A total of 1,736 questionnaires were collected and prescreened based on the respondents' m-learning experiences. Subsequently, 174 incomplete responses were rejected, leaving 1,562 valid questionnaires for formal data analysis.

The demographic characteristics of the respondents are presented in **Table 1**. The data revealed that the mean age of the participants was 19.6 years (standard deviation: 1.4 years). Approximately two-thirds of the participants were women (67.0%). In addition, 37.1% of the sample were from management colleges. Approximately 45% of the participants were in their first year in college.

RESULTS

Data Analysis

Partial least squares (PLS) regression is one of the most commonly adopted structural equation modeling (SEM) techniques used to validate structured data. PLS regression is especially effective for data analysis during the early stages of theory development when the theoretical model and its measures are not yet complete (Tsang, 2002). The PLS model analyzes and interprets the reliability and validity of (1) the measurement model and (2) the structural model. In this study, PLS regression was used to perform bootstrapping for our research model and to test and validate the proposed model and the relationships among the hypothesized constructs.

TABLE 1 | Profile of Respondents (*N* = 1,562).

Demographics/ Level	*N*	Percentage	Demographics/ Level	*N*	Percentage
Gender			**Year in college**		
Male	516	33.0	First	702	44.9
Female	1046	67.0	Second	444	28.4
College			Third	225	14.4
College of Science and Engineering	288	18.4	Fourth	191	12.2
College of Humanities and Social Sciences	335	21.4			
College of Design	359	23.0			
College of Management	580	37.1			

Measurement Model Evaluation

The measurement model was assessed by examining the internal reliability, convergent validity (CV), and discriminant validity (DV). The internal reliability was evaluated by examining the Cronbach's alpha and composite reliability (CR) values for all constructs. CV was assessed by measuring the average variance extracted (AVE). Accordingly, the three most commonly used evaluation indicators were selected (Fornell and Larcker, 1981; Chin, 1998; Jöreskog and Sörbom, 2005; Hair et al., 2010; Bagozzi and Yi, 2012), include: Cronbach's alpha, composite reliability (CR), and average variance extracted (AVE). The item loading range, Cronbach's alpha, AVE, and CR results are presented in **Table 2**.

In **Table 2**, the estimated construct loadings range from 0.681 to 0.960, and thus are higher than the recommended levels (Hair et al., 2010). Construct reliability indicates how well a construct is measured by its items, and can be assessed based on Cronbach's alpha and CR. The Cronbach's alpha values ranged from 0.70 for PR to 0.90 for satisfaction, and CR values ranged from 0.761 for PR to 0.928 for satisfaction. For both measures, all constructs exceeded the recommended cutoff of 0.7 (Fornell and Larcker, 1981; Hair et al., 2010), thereby suggesting high internal reliability. **Table 2** reveals that the estimated latent construct factor loadings ranged from 0.68 to 0.96 and were statistically significant ($p < 0.05$). The AVE ranged from 0.584 (EE) to 0.772 (BI) and was greater than 0.5 for each construct (Fornell and Larcker, 1981), thereby indicating CV.

To evaluate the DV, the square root of the AVE of each latent construct was compared with its interconstruct correlation. The square root of the AVE of a construct should be greater than its correlations with other constructs to achieve satisfactory DV (Fornell and Larcker, 1981; Hair et al., 2016). Additionally, the diagonal values should be higher than the off-diagonal values in the corresponding columns and rows (Henseler et al., 2009). As shown in **Table 3**, for each construct, the square root of the AVE (shown diagonally with bold values) exceeded the inter-construct correlations, thereby indicating an appropriate level of DV.

TABLE 2 | Construct Reliability Results.

Construct	No. of items	Item loading	Cronbach's α	AVE	CR
Perceived Enjoyment (PEN)	3	0.79–0.85	0.76	0.675	0.861
Effort Expectancy (EE)	5	0.73–0.80	0.82	0.584	0.875
Performance Expectancy (PE)	4	0.70–0.82	0.77	0.589	0.851
Satisfaction (SAT)	5	0.84–0.88	0.90	0.722	0.928
Trust (TRU)	5	0.77–0.88	0.89	0.694	0.919
Mobile Self-efficacy (M-SE)	3	0.85–0.88	0.82	0.736	0.893
Perceived Risk (PR)	3	0.68–0.96	0.70	0.629	0.761
Behavioral Intention (BI)	3	0.86–0.89	0.85	0.772	0.910

AVE, Average Variance Extracted; CR, Composite Reliability.

TABLE 3 | Correlation matrix and square root of the AVE.

Construct	Mean	SD	PEN	EE	PE	SAT	TRU	M-SE	PR	BI
PEN	3.47	0.70	**0.82**							
EE	3.54	0.65	0.46*	**0.76**						
PE	3.63	0.63	0.47*	0.57*	**0.77**					
SAT	3.41	0.68	0.54*	0.52*	0.50*	**0.85**				
TRU	3.25	0.69	0.45*	0.57*	0.43*	0.61*	**0.83**			
M-SE	3.93	0.70	0.51*	0.46*	0.46*	0.37*	0.25*	**0.86**		
PR	2.09	0.71	−0.20*	−0.12*	−0.22*	−0.05*	−0.05*	−0.29*	**0.79**	
BI	3.34	0.77	0.57*	0.47*	0.49*	0.63*	0.51*	0.40*	−0.08*	**0.88**

*SD, Standard deviation; Bolded values on the diagonal are the square root of the AVE. Values on the off-diagonal represent inter-construct correlations. PEN, Perceived enjoyment; EE, Effort expectancy; PE, Performance expectancy; SAT, Satisfaction; TRU, Trust; M-SE, Mobile self-efficacy; PR, Perceived risk; BI, Behavioral intention. *$p < 0.05$.*

Statistical Analysis and Hypotheses Testing

Partial least squares regression was used to test the main effects of EE and PE and the moderating effect of PR on BI to use m-learning (**Figures 3**, **4**, respectively). For example, to test the moderating effect, PE (predictor) and PR (moderator) were multiplied to create an interaction construct (PE × PR) for predicting BI to use m-learning.

Regarding the overall quality of the research model, the SEM procedure based on PLS regression was applied to analyze the goodness of fit (GoF), path coefficients, and coefficient of determination (R^2). The GoF ($0 < \text{GoF} < 1$) is considered the geometric mean of the average commonality and average R^2 value. To measure the GoF, this study used the equation employed by Alolah et al. (2014): $\text{GoF} = \sqrt{\overline{AVE} \times \bar{R}^2}$. In our study, the GoF value was 0.502, which exceeded the 0.36 benchmark suggested by Tenenhaus et al. (2005). Thus, the proposed model had good overall fit, indicating that it performed well compared with the aforementioned baseline values.

This study tested the relationships between dependent and independent variables by using the path coefficient (β) and t statistics. By using PLS regression to estimate the path relationship of each pair of research constructs, among all eight path relationships, we revealed that seven assumptions attained significance. Bootstrapping resampling was performed to test the significance of the path coefficients in the inner model (number of iterations: 1000).

To verify the hypotheses and moderating effects, the moderator analysis method proposed by Baron and Kenny (1986) was followed. The empirical analysis determined the moderating roles of PR based on the significance of the interaction terms in Model 3. Among the two hypothesized moderating effects, M1 was non-significant; that is, PR did not have moderating effect on the relationship between EE and BI. However; PR negatively moderated the relationship between PE and BI in relation to m-learning use (M2: $\beta = -0.15$, $p < 0.05$); this finding indicates that M2 was significant. These additional analyses provided support for the moderation pattern presented in our model. **Figure 5** provides all results of the moderation analysis, including

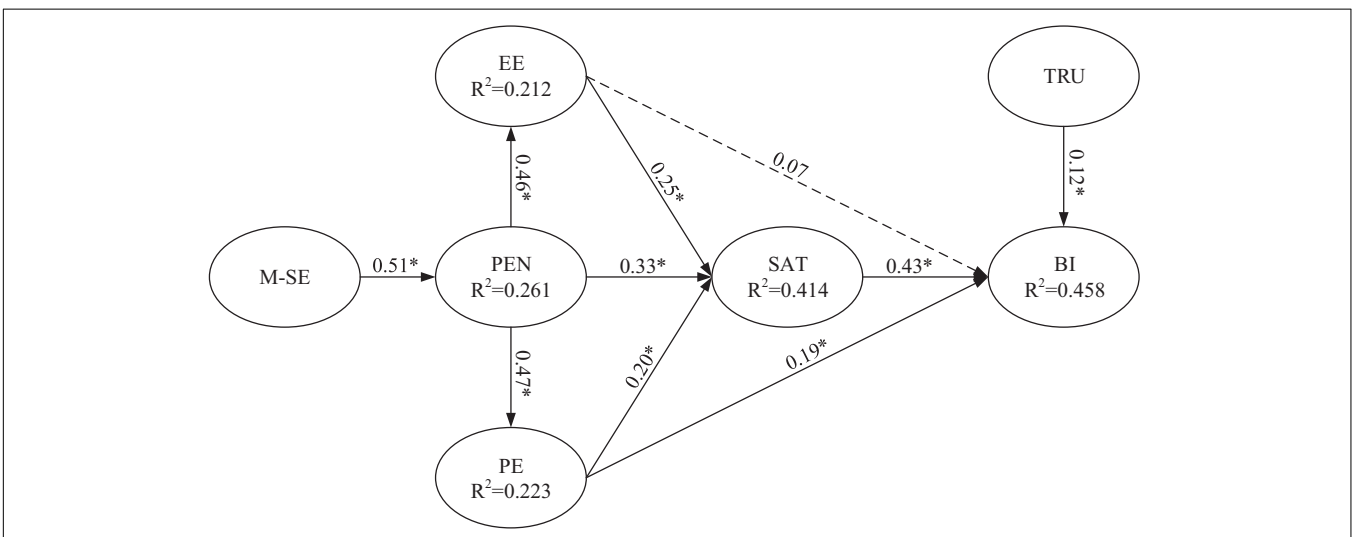

FIGURE 3 | Path coefficients for the research model (excluding moderator main effect). Value on path: standardized coefficients (β), R^2: Coefficient of determination and *$p < 0.05$.

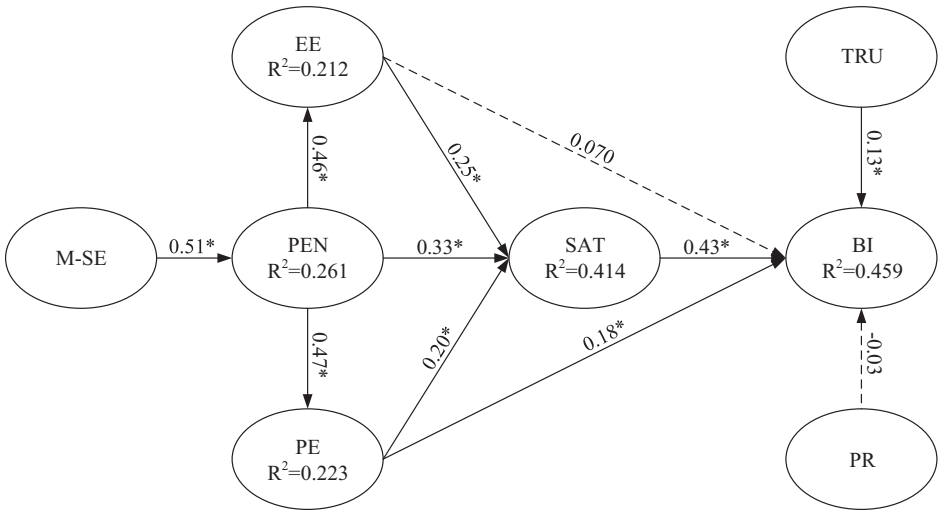

FIGURE 4 | Path coefficients for the research model (including moderator main effect). Value on path: standardized coefficients (β), R^2: Coefficient of determination and $^*p < 0.05$.

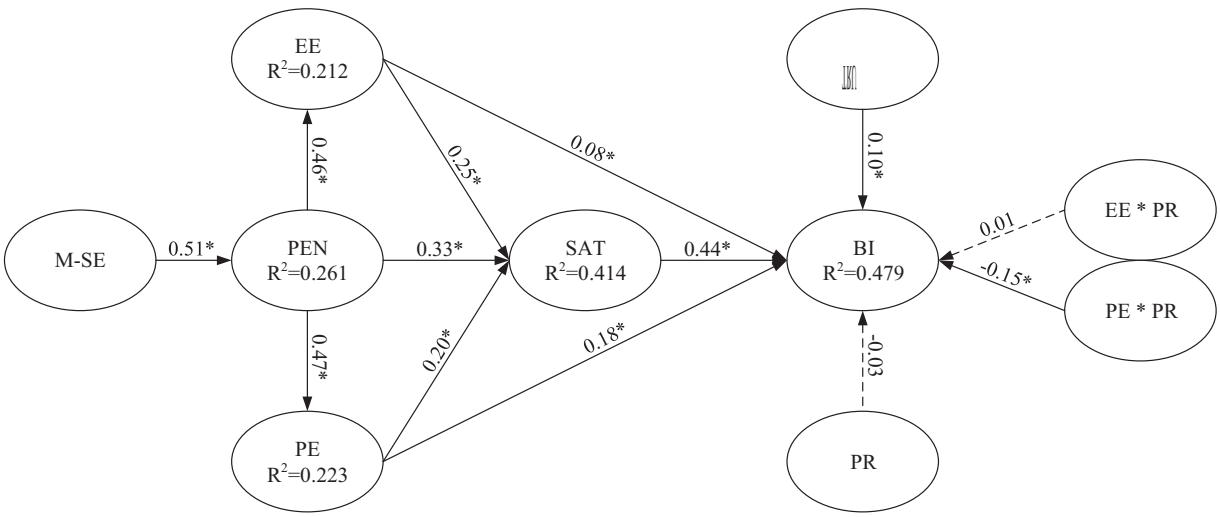

FIGURE 5 | Path coefficients for the research model (including interaction effect). Value on path: standardized coefficients (β), R^2: Coefficient of determination and $^*p < 0.05$.

the structural path estimates and explained variances. Consistent with M2, PE and PR had a negative effect on BI to use m-learning. Specifically, we revealed that PE and BI related to m-learning increased with a decrease in PR.

Regarding the components of the UTAUT model, EE and PE had significantly positive effects on BI to use m-learning (β = 0.08 and 0.18, respectively, $p < 0.05$). Therefore, Hypotheses 1 and 2 were supported. In addition, satisfaction and trust had significant positive effects on BI (β = 0.44 and 0.10, respectively, $p < 0.05$), thereby supporting Hypotheses 3 and 4. EE, PE, and perceived enjoyment were all crucial antecedents of satisfaction (β = 0.25, 0.20, and 0.33, respectively, $p < 0.05$). The results for the prediction of satisfaction were consistent with the EE, PE, and perceived enjoyment hypotheses adapted to the context; thus, Hypotheses 5, 6, and 7 were supported. Perceived enjoyment was a significant determinant of EE and PE (β = 0.46 and 0.47, respectively), thereby supporting Hypotheses 8 and 9. Finally, mobile self-efficacy was a significant determinant of perceived enjoyment (β = 0.51, $p < 0.05$), and thus Hypothesis 10 was supported.

Figure 5 presents the explanatory power. The model explained a substantial portion of the variance in all endogenous variables: EE (21.2%), PE (22.3%), perceived enjoyment (26.1%), satisfaction (41.4%), and BI (47.9%). Falk and Miller (1992) asserted that the coefficient of determination (R^2) should be higher than 0.10; all the endogenous variables in our study

satisfied this requirement. However, a substantial portion of unexplained variances indicated that other key factors beyond the scope of this study could be incorporated to improve the explanatory power of the endogenous variables. In summary, the model employed in this study explained a considerable number of variations in the endogenous variables. The endogenous variables exhibited strong explanatory power for these variations, thereby indicating the stability and robustness of the model. All estimated and standardized path coefficients (significant paths are indicated with asterisks) are illustrated in **Figure 5**.

DISCUSSION

The purpose of this study was to identify factors that affect university students' BIs to use m-learning. The research model presented in this paper is unique in its integration of perceived enjoyment, mobile self-efficacy, satisfaction, trust, PR, and BI into the UTAUT model to evaluate the determinants of users' BIs toward m-learning. This model examined whether PE, EE, and PR moderated and predicted BI. The results of a cross-sectional online survey of 1,562 participants demonstrated that the fundamental determinants of BI were, in order of relevance, satisfaction, PE, trust, and EE. In addition, the results revealed positive influences of perceived enjoyment, PE, and EE on satisfaction. The negative moderating role of PR on the relationship between PE and BI was also revealed. An interpretation of the results based on the empirical findings is presented as follows.

The research model explained 47.9% of the variance in BI. The most crucial factors that influenced BI were satisfaction, PE, trust, and EE. Satisfaction and trust had direct effects on BI to use m-learning; this was consistent with the findings of another study (Koufaris and Hampton-Sosa, 2004; DeLone and McLean, 2016; Kabra et al., 2017). Therefore, satisfaction and trust are crucial predictors of individuals' BIs to adopt ISs or IT. The Taiwanese government has been promoting online learning in primary and secondary education since 1996 to cultivate literacy in IT and improve students' international competitiveness. Consequently, most current students have been receiving IT education since the third or fourth grade; this policy has equipped students with the basic ability to adapt to changes in technology. In this study, all participating students had received IT education at elementary school. As technology continues to evolve, students learn not only through face-to-face teaching and e-learning systems but also increasingly through m-learning. Many students have realized the advantages of e-learning and m-learning. In particular, m-learning fits students' requirements to learn without time and space limitations. In the contemporary world, m-learning is relatively accessible, thereby providing a favorable m-learning environment and promoting students' BIs. Thus, the higher students' satisfaction and trust toward m-learning, the higher are their BIs. The findings of the study confirmed that PE and EE had significantly positive effects on BI; this was in accordance with the findings of other studies (Venkatesh et al., 2003; Šumak and Šorgo, 2016; Hoque and Sorwar, 2017; Khalilzadeh et al., 2017; Šumak et al., 2017). In addition, the results of our analysis highlighted the fundamental role of PE. We revealed that PE, alongside perceived enjoyment and EE, is positively associated with satisfaction with m-learning. This indicates that perceived enjoyment had a significantly positive effect on satisfaction with m-learning, which corresponds with the findings of Shiau and Luo (2013). Furthermore, we demonstrated that the effects of PE and EE on satisfaction with m-learning were significant and positive; this is similar to the findings of Maillet et al. (2015). Based on the findings of the present study, m-learning is an increasingly crucial method of learning for students. When students find m-learning engaging and easy to use and consider it to improve their learning performance and effectiveness, their satisfaction toward m-learning and their BIs toward using it are enhanced. Therefore, regarding the future development of m-learning, schools and other educational institutions are recommended to provide online forums for learners to communicate and share what they have learned. This measure could promote diversity with respect to m-learning and increase students' satisfaction and BIs to use it.

Most related studies (Sánchez-Prieto et al., 2016; Chang et al., 2017; Tsai et al., 2018) have argued that perceived enjoyment is a crucial external factor that significantly affects the PU and PEOU of m-learning. However, to our knowledge, no studies have investigated the effects of perceived enjoyment on PE and EE; thus, a theoretical foundation is yet to be built. The findings of this study demonstrated that perceived enjoyment significantly influenced PE and EE. Therefore, perceived enjoyment is a key external variable in the UTAUT model. In addition, no study has examined the possible effect of mobile self-efficacy on perceived enjoyment. The result obtained in the present study indicated that mobile self-efficacy had a significantly positive effect on perceived enjoyment. We expanded the use of mobile self-efficacy and perceived enjoyment. With the popularity of the Internet and mobile devices for various uses (e.g., mobile payments, banking, and mobile health), university students have high mobile self-efficacy and gain enjoyment from using their mobile devices. As m-learning becomes an increasingly dominant method of learning, students' enjoyment of it is expected to increase. Students not only find m-learning easy to use but also acknowledge the importance of learning.

In this study, PR was tested as a moderator; the results revealed that it significantly and negatively moderated the relationship between PE and BI. This significant relationship indicated that (1) PR as a moderating variable provided a robust basis for our hypotheses, and (2) PR was a critical moderating variable for m-learning usage in our extended UTAUT model. However, PR did not have a moderating effect on the relationship between EE and BI. According to our findings, if university students perceive m-learning as easy to use, their level of PR plays no fundamental role in the decision to use it. However, the relationship between PR and BI was non-significant; this finding differs from that obtained by Alalwan et al. (2018). Based on our findings, in addition to their basic understanding of m-learning, students are aware of solutions (e.g., system instruction, FAQs, and online forums) to potential risks and problems and that the privacy and safety of systems have been improved in recent years.

These factors can lower students' PR. Therefore, PR did not have a significant influence on BI. Notably, when using m-learning, students worry about problems that could hinder their learning (e.g., Internet stability and whether they have successfully uploaded assignments and updated data), thereby increasing PR and reducing BI. Thus, schools and system developers should establish a feedback mechanism through which students can find out whether their assignments were successfully uploaded to the system7; this measure could lower PR and increase BI.

LIMITATIONS AND FUTURE RESEARCH

This study had several limitations that could be addressed in future studies. First, the results were based on university students, and thus could benefit from comparison with results obtained from the same model aimed at students from a wider variety of educational levels (e.g., senior and vocational high school students). Second, this study was cross-sectional in nature and conducted within a short period. Students' perceptions of EE, PE, satisfaction, trust, and BI toward m-learning can change over time as new knowledge and experiences are accumulated. Therefore, future studies could employ a longitudinal design to obtain more accurate findings from a specific group. Finally, although the moderator of this study was PR, other variables such as system quality, trust, and mobile information literacy may also moderate the relationship between BI and another factor/variable. Thus, these variables should be considered as moderators in future studies. Finally, this study used a self-reported questionnaire as the research tool. In a questionnaire, when answering questions, interviewees might not express their true opinions, and this could lead to errors in the results. This problem should be handled cautiously when interpreting research data.

CONCLUSION

This study developed a novel integrative model to explain the determinants of university students' BIs toward using m-learning at an individual level. A conceptual model was built based on the UTAUT model in to extend this adequately validated framework by incorporating five additional predictor variables (i.e., mobile self-efficacy, perceived enjoyment, satisfaction, trust, and PR). Data were collected from 1,562 participants with experience in using m-learning. The results revealed that the model had high internal consistency and reliability, thereby indicating that the proposed model possesses substantial explanatory power. This study revealed that satisfaction is a key factor that significantly influences university student's BIs toward using m-learning. In addition, the results revealed positive influences of PE, trust, and EE on BI. Students' perceived enjoyment was a key factor that affected PE, EE, and satisfaction. Mobile self-efficacy had a significant positive effect on perceived enjoyment. Finally, PE and PR had a negative interaction effect on BI to use m-learning. Determining what motivates use of new technologies can improve learning quality and boost pedagogical and instructional uses of said technologies. The findings of this study could be of value for decision-makers in educational institutions.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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APPENDIX

TABLE A1 | Measurement Items.

Constructs	Items	Mean	SD
Effort Expectancy	Learning how to use mobile learning is easy for me.	3.58	0.84
	My interaction with the mobile learning would be clear and understandable.	3.47	0.91
	I find mobile learning easy to use.	3.71	0.80
	It is easy for me to become skilful at using mobile learning.	3.62	0.82
	I would find it easy to get the mobile learning to do what I want it to do.	3.33	0.89
Performance Expectancy	Using the mobile learning would improve my learning performance.	3.61	0.79
	Using mobile learning increases my chances of achieving learn that are important to me.	3.55	0.83
	Using the mobile learning would allow me to accomplish learning tasks more quickly.	3.72	0.86
	Using the mobile learning would enhance my effectiveness in learning.	3.65	0.79
Perceived Enjoyment	I find using mobile learning enjoyable.	3.36	0.90
	The actual process of using the mobile learning is pleasant.	3.49	0.81
	I have fun using the mobile learning.	3.56	0.83
Satisfaction	I was very content with mobile learning.	3.44	0.77
	I was very pleased with mobile learning.	3.36	0.77
	I was satisfied with mobile learning efficiency.	3.38	0.79
	I felt delighted with mobile learning.	3.43	0.86
	Overall, I was satisfied with mobile learning.	3.44	0.81
Trust	I believe that mobile learning is trustworthy.	3.30	0.78
	I trust in mobile learning.	3.30	0.79
	I do not doubt the honesty of mobile learning.	3.30	0.85
	Even if not monitored, I would trust mobile learning to do the job right.	3.24	0.79
	Mobile learning has the ability to fulfill its task.	3.10	0.93
Mobile Self-efficacy	I am confident of using the mobile learning even if there is no one around to show me how to do it.	3.86	0.84
	I am confident of using the mobile learning even if I have never used such a system before.	3.96	0.79
	I am confident of using the mobile learning even if I have only the software manuals for reference.	3.97	0.81
Perceived Risk	I think using mobile learning puts my privacy at risk.	3.99	0.86
	Using mobile learning exposes me to an overall risk.	3.99	0.84
	Using mobile learning will not fit well with my self-image.	3.83	0.87
Behavioral Intention	Assuming I had access to the mobile learning, I intend to use it.	3.16	0.92
	Given that I had access to the mobile learning, I predict that I would use it.	3.46	0.82
	I plan to use the mobile learning in the future.	3.39	0.87

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Differences in Personal, Familial, Social, and School Factors Between Underachieving and Non-underachieving Gifted Secondary Students

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Using various identification methods, differences between underachieving and non-underachieving gifted students in personal, familial, social, and school variables were analyzed in a sample of 164 gifted students with IQs of 120 or higher; the sample was drawn from a larger sample of 1,400 compulsory secondary education students. Three procedures for identifying underachieving students were used: the standardized difference method, the regression method, and the Rasch method. The different profiles of underachieving and non-underachieving students in the personal, familial, social, and school variables were compared using MANOVA and ANOVA tests. Results revealed that underachieving gifted students scored significantly lower in learning strategies, goal orientations, self-concept, attitudes toward teachers, and perceived parent involvement in school variables. These results have clear educational implications as a result of identifying differences in non-cognitive factors.

Keywords: gifted students, underachievement, identification methods, academic achievement, individual characteristics, social characteristics, parent involvement

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INTRODUCTION

In the field of education, the term underachievement has received increasing attention in recent decades. It provides methods for both its detection and the correct identification of the cognitive and non-cognitive variables involved (Lau and Chan, 2001; McCoach and Siegle, 2003a,b, 2011; Matthews and McBee, 2007). The first issue concerning underachievement is the definition, given the fact that there is no consensus on it (McCoach and Siegle, 2011). From the scientific literature, it is clear that underachievement refers to students whose achievement is lower than expected based on their cognitive abilities (McCoach and Siegle, 2003b; Phillipson, 2008).

Underachievement studies, especially in the United States (US), have traditionally focused on gifted students (Reis and McCoach, 2000; Obergriesser and Stoeger, 2015), whereas those in China have considered all ranges of ability (Phillipson, 2008, 2010; Dittrich, 2014).

The three statistical methods conventionally used for identifying underachieving students include the absolute split method, the simple standardized difference method, and the regression method (Lau and Chan, 2001; McCoach and Siegle, 2011). For the absolute split method, discretionary cut-off scores are used for the highest mental ability (for example, the highest 5%)

and the lowest academic performance (for example, the lowest 5%) once the punctuations have been converted into standard scores. The simple standardized difference score method analyses the distance between the standardized performance score and the standardized ability score. If this distance exceeds the discretionary margin (usually 1 standard deviation or SD), a student can be considered as underachieving ($d < -1$) or overachieving ($d > 1$). McCall et al. (1992) pointed out that the simple standardized difference score method can produce overestimation of these types of students in the high and low ability ranges. One of the most common methods for identifying underachievement is the regression method (Lau and Chan, 2001; McCoach and Siegle, 2011), which analyses the deviations of students' scores from the regression line of the measure of performance according to the measure of capacity. These statistical methods are based on the use of arbitrary cutoffs, as well as the use of standardized transformations that do not suppose the assumption that the original data are interval in nature (Fletcher et al., 2005; Phillipson, 2008) and generate a uniform percentage of underachieving students (Plewis, 1991; Ziegler et al., 2012).

To improve the objective use of the interval scale, the latest method employed in identifying underachieving students is the Rasch model (Phillipson and Tse, 2007; Phillipson, 2008). This model supposes that the probability of a given subject/item interaction is only controlled by the difficulty of the item and the ability of the subject, which are conditioned by the item situations of the supposed latent variables along the same scale structure (Wright and Stone, 1979; Rasch, 1980; Bond and Fox, 2007). Therefore, using the same measurement scale establishes homogeneous intervals, implying the same differences between item parameters and person ability and therefore the same probability of success (Preece, 2010). The adjustment of this interaction can be performed by employing residual measures and standardized punctuations for a specific item or subject (Bond and Fox, 2007).

Veas et al. (2016a) compared the statistical methods employed for detecting underachievement (the standardized difference method, the regression method, and the Rasch method) in a sample of 1,182 first- and second-year secondary students from eight secondary schools in Spain. The results showed varying percentages of underachieving students that included 14.55% (simple standardized difference), 15.39% (regression method), and 30.37% (Rasch model), depending on the statistical method employed; boys showed higher percentages (65%) than girls.

Theoretical Framework

During the last years, important advances have been made to understand underachievement as an integrated and explanatory model, especially from the gifted education perspective. In this context, the actiotope model of giftedness (Ziegler, 2005) constitutes an appropriate framework that tries to explain how external and internal variables relate to each other.

Ziegler and Stoeger (2017) use the term "actiotope" to consider a student as the unit of analysis. An actiotope can be defined as a dynamic and personal perspective in a specific environment. Exogenous resources are important to build actiotopes' action repertoires in educational contexts. Concretely, when exogenous resources enter the actiotope, they are referred to as educational capital (Ziegler and Baker, 2013). Educational capital is defined as all the resources that can be used to promote learning. Five types of educational capital have been proposed: economic educational capital (wealth, possessions, money, or valuables that can be invested), cultural educational capital (value systems, thinking patterns, and models), social educational capital (people and social institutions), infrastructural educational capital (materials implemented in learning), and didactic educational capital (design and improvement of education and learning processes).

Additionally, endogenous resources also affect individual functioning, which is called learning capital. Again, these resources are organized into five types: organismic learning capital (a person's physiological and constitutional resources), telic learning capital (a person's anticipated goal states that satisfy their needs), actional learning capital (the totality of actions that a person is able to perform), episodic learning capital (the simultaneous goal- and situation-relevant action patterns that are accessible to a person), and attention learning capital (the quantitative and qualitative attentional resources that a person can apply to learning).

Personal Factors Involved in Underachievement

Regarding personal factors, Colangelo et al. (2004) found that using self-regulation strategies, learning strategies, and study techniques explicate the differences between high achievement and low achievement in high-ability students.

Studies from the US and China have detected minor levels of motivation associated with underachievement (Schick and Phillipson, 2009; Dunlosky and Rawson, 2012). McCoach and Siegle (2003a) found that gifted underachieving students differed in their school attitudes, attitudes toward teachers, motivation, self-regulation, and valuation objectives.

Meanwhile, the role of self-concept in the underachievement process is not clear (Preckel and Brunner, 2015). Several studies have reported poorer academic self-concept in underachievers (Rimm, 2003) and poorer general self-concept but not poorer academic self-concept in gifted underachievers (McCoach and Siegle, 2003a).

Castejón et al. (2016) explained the different learning strategies, goal orientations, and self-concepts of overachieving, normally achieving, and underachieving students in secondary education using a sample of 1,400 Spanish students. The results indicated that overachieving students reported significantly better scores than underachieving students in learning strategies and goals, academic self-concept, personal self-concept, relationship with parents, honesty, and personal stability. Along the same lines, Heyder et al. (2017) analyzed the variables involved in underachievement in boys' language skills, finding that self-concept, motivation, previous performance, and family characteristics were key variables in the explanation of underachievement.

Family and Social Factors Involved in Underachievement

Regarding family and social factors, the results obtained by Phillipson (2010) showed the relevance of these factors in the academic achievement of children, despite the children's intellectual capacities. In high- and medium-ability students, parental expectations influenced the students' achievement through the students' ability, while in low-ability students, parental expectations influenced students' achievement in a direct way. There are some studies analyzing parental influence on the achievement or underachievement of their children (Rimm and Lowe, 1988; Yazdani and Daryei, 2016). Certain patterns of familial settings may be related to underachievement (Baker et al., 1998; Rimm and Lowe, 1988). Parents of high-performing students show interest in academic achievement, while parents of underachieving students often show disinterest in school and education.

Reis and McCoach's (2000) review of family factors showed that most studies of underachieving students focus on gifted students' family structures and environments; parents' involvement is highly important to education and academic performance. The perception that parents have similar ability as their children influences their children's self-concepts, motivation, and, therefore, their performance (Simpkins et al., 2015). However, Jeynes (2005, 2012) pointed out the necessity of deepening the analysis of the role of parent involvement in the education of underachieving students.

McCoach and Siegle (2003a) attribute some of the differences between underachieving and non-underachieving students in students' attitudes toward school and teachers. Gifted achieving students show differences in attitudes toward school, attitudes toward teachers, motivation/self-regulation, and goal valuation in comparison with gifted underachieving students. The findings obtained by Miñano et al. (2014) found that underachieving students showed the lowest levels of academic self-perception, attitudes toward school, attitudes toward teachers, motivation/self-regulation, and goal valuation.

Social factors, such as peer acceptance, may also promote achievement and underachievement (Reis and McCoach, 2000); negative peer attitudes can often explain underachievement. Negative attitudes of peers are usually related to underachievement, while popularity is often related to greater motivation, greater feelings of belonging at school, and higher academic performance (Wentzel et al., 2005).

The Present Study

The first objective of this study was to compare these differences between underachieving and non-underachieving students using the standardized difference, the residual of regression, and the Rasch method of identification of underachieving students. With respect to giftedness, the identification methods of gifted students have generated a great deal of discussion (Brown et al., 2005). In the process of identification, a number of methodological aspects have been included, such as description of indicators, ways of obtaining information, and measurement questions (Heller and Schofield, 2008).

In relation with this objective, it is hypothesized (H1) that significant differences exist in the percentage of underachieving gifted students between the Rasch method and the other two methods (the simple difference method and the regression method).

The second objective was to examine the differences of educational capital and learning capital resources between underachieving and non-underachieving gifted students, which include personal, family and social variables. According to the literature, there are diverse reasons for underachievement as a school or family adjustment-related problem (Baker et al., 1998; McCoach and Siegle, 2003b) or personal attribute, such as low motivation or low self-concept (Reis and McCoach, 2000; Peixoto and Almeida, 2010; Dunlosky and Rawson, 2012; White et al., 2018). Baker et al. (1998) proposed a three-factor model to explain underachievement in American adolescent students and found that the variables that made the greatest contribution to the explanation of the differences between high- and low-performance students were self-regulation strategies, ability self-perception, and teacher-student relations (quality). Knowledge of these different characteristics is important to reverse underachievement (Renzulli and Reis, 1997; Chan, 1999, 2005).

With respect to the existing differences between underachieving and non-underachieving gifted students, it is expected that underachieving gifted students have significantly minor scores than non-underachieving gifted students on all of the studied variables (H2a), with the exception of achievement goals, social reinforcement goals, and general social self-concept, on which they are expected to have significantly higher scores (H2b).

MATERIALS AND METHODS

Participants

This study used random cluster sampling with schools as the sampling unit, focusing on southeastern Spain. A total of 1,400 students in the first and second years of compulsory secondary education participated. Of those, 81.4% were enrolled in public school and 18.6% were enrolled in private school. Childhood socioeconomic status (SES) was established based on parents' occupations, family incomes, and educational histories. There was a wide range of SESs; middle-class children made up the majority.

With reference to gender, 51.2% were boys and 48.8% were girls; the gender makeup in the national student population was 51.3% boys and 48.7% girls, and a chi-square test showed no gender differences between the sample and the population ($\chi 2 = 0.29$, df = 1, $p > 0.01$).

From the total sample, 164 participants with an IQs of 120 or higher (as measured by a test of intelligence) were selected, taking as reference the national normative published in the test manual. This subsample accounted for 11.71% of the total sample. Of these 164 students, 95 (57.9%) were males and 69 (42.1%) were females. There were statistically significant differences between the percentage of males and the percentage of females ($\chi 2 = 4.12$; $p = 0.04$).

Measures

General Intellectual Ability

General intellectual ability was estimated using the Battery of Differential and General Abilities (BADyG) (Yuste et al., 2005), which evaluates students' capacities and academic abilities using 192 items. Each item has five response options (only one correct response option) and offers a general intelligence quotient (IQ). The Cronbach's alpha of the total IQ was 0.83.

Self-Concept

Marsh's (1990) Self-Description Questionnaire (SDQ-II), which was adapted into Spanish (the Self-Concept Evaluation Scale for Adolescents [ESEA-2]) by González-Pienda et al. (2002), was employed to evaluate self-concept. This instrument comprises 70 items grouped into 11 self-concept dimensions, which are then grouped into three general dimensions; these were used in the present study and include general academic self-concept, general social self-concept, and general private self-concept. In the authors' validation, all Cronbach's alpha values were between 0.73 and 0.91. The answers were given on a 6-point Likert scale (1 = totally disagree, 6 = totally agree) to indicate the degree of agreement or disagreement with each statement.

Goal Orientation

García et al. (1998) Academic Goal Questionnaire (CMA), which is a Spanish adaptation of the Achievement Goal Tendencies Questionnaire by Hayamizu and Weiner (1991), was used to evaluate goal orientation. This instrument comprises 20 items grouped into three goals: learning, performance, and reinforcement. The answers are given on a 5-point Likert scale (1 = never, 5 = always), depending on the frequency with which the subject feels the statement to be true. In our sample, the Cronbach's alpha values were 0.75, 0.72, and 0.85 for each of the three goals, respectively.

Learning Strategies

Learning strategies were measured using the Learning Strategies Questionnaire (CEA), produced by Beltrán et al. (2006), which evaluates four large scales. We only used the elaboration of information, personalization, and meta-cognition scales. To evaluate these three scales, students answered 50 items on a 5-point Likert scale (1 = completely false, 5 = totally true), indicating the degree to which each strategy was applicable to their own learning. We obtained Cronbach′s alpha values of 0.71–0.87.

Attitudes to School and Teachers

The Spanish adaptation of the School Attitude Assessment Survey-Revised (SAAS-R) by Miñano et al. (2014) was utilized to measure attitudes to school and teachers. The instrument was originally designed by McCoach and Siegle (2003b). The scale is made up of 35 items answered on a 7-point Likert scale; it measures five factors: AS, Academic Self-Perception, which explored students' perception of the academic ability; ATT, Attitudes toward Teachers, which consisted of the students' self-reported interest in their teachers and classes; ATS, Attitudes toward School, which consisted of the students' self-reported interest in and affect toward school; GV, Goal Valuation, employed to measure students' valuing of the goals of school; and M/S, Motivation/Self-Regulation, including the strategies employed to show high level of interest and to regulate cognition and effort (Pintrich and De Groot, 1990, p. 33). The reliability, or Cronbach's alpha, obtained in the sample of 1,400 Spanish secondary school students was 0.86, 0.87, 0.90, 0.85, and 0.90 for each of the five factors, respectively.

Popularity

The popularity variable was measured using the BULL-S, as elaborated by Cerezo (2000). This instrument comprises 15 items. In this study, we used only the first four ("who would you choose as a classmate?," "who would you not choose as a classmate?," "who do you think has chosen you?," "who do you think has not chosen you?") to extract an index of peer acceptance (popularity).

Parent Involvement

The Parental Involvement Questionnaire (CIF) was used to evaluate the participation of parents. This questionnaire was created by our research group. Through this questionnaire, the students reported their perceptions of parental participation and monitoring and the importance that their parents place on the educational process. The instrument comprises 20 items grouped into four factors: (a) perception of support, planning, and interest in scholastic development ("I believe that my parents help me with my studies as much as they can"); (b) parental expectations ("my parents believe I can continue on to pursue post-compulsory education, i.e., high school or intermediate vocational training"); (c) school relations ("my parents regularly attend parent-tutor meetings"); and aid with homework ("my parents assist me with questions, homework, internet research, etc."). Students answered the items on a 5-point Likert scale (1 = never or hardly ever, 5 = always or mostly), indicating the frequency that each statement is true. Cronbach's alphas were 0.70, 0.65, 0.65, and 0.71 for each of the four factors, respectively.

Academic Achievement

To measure academic achievement, the mean GPAs from seven mandatory courses were employed. The courses registered were Spanish Language and Literature, Natural Sciences, Catalan Language, Social Sciences, Mathematics, English, and Technology. Grades from Art Education and Physical Education were discarded because of their lack of unidimensionality and also to investigate differences according to gender in this sample (Veas et al., 2017). The student scores showed high reliability, with a Cronbach's alpha value of 0.94.

Procedure

Mandatory consent was first obtained from the administrative staff and school boards of the schools, and the parents or legal guardians of the students then provided written informed consent. Data collection took place at the schools throughout the second trimester of the school year and during normal school hours over 4-h sessions. This study was approved by our Institutional Review Board and followed the ethical standard

of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Data Analysis

The simple standardized difference method was calculated based on the discrepancy between the standardized performance score and the standardized ability score. The students with a difference in punctuation lower than −1 were identified as underachieving. Secondly, the regression method was performed, with total IQ from the BADyG as the predictor and average grade of each student as the criteria. Students showing residual punctuation lower than −1 were identified as underachieving. SPSS version 21.0 software was used for both methods.

For the identification of underachieving students with the Rasch method, IQ scores from the BADyG and school grades were analyzed employing Winsteps version 3.81 statistical software (Linacre, 2011), and the estimates were based on the joint maximum likelihood (Linacre, 2012). Once fit indices from both measures have been obtained, the Rasch model allows for testing the hypothesis that two tests measure the same underlying construct (Bond and Fox, 2007). The procedures and results of these analyses are described in detail by Veas et al. (2016a,b).

To compare the profiles of the underachieving and non-underachieving students, a GLM (General Linear Model) was performed, which is a widely used procedure in profile analysis (Tabachnick and Fidell, 2007). Because not all of the variables were measured on the same scale, all of the scores were converted into z scores. Once the sample sizes were unequal, homogeneity (Box M) was tested. These analyses were performed with SPSS version 22.0.

RESULTS

Table 1 shows the number and percentage of underachieving and non-underachieving students identified by each method within the sample of high-ability students with IQs equal or superior to 120. From the 1,400 secondary school students who composed the sample of participants, 164 (11.71%) had IQs of 120 or above. Of these 164 high-ability students, 95 (57.9%) were male and 69 (42.1%) female, which was a slightly significant difference in percentage ($\chi 2 = 4.12$, $p = 0.04$).

As can be observed, the numbers and percentages of subjects identified as underachieving were considerably different depending upon method of identification, becoming statistically significant (Cochran $Q = 34.66$, $p = 0.001$). The standardized difference method identified a greater number of underachieving students than the regression and the Rasch methods; the Rasch method identified a smaller number of underachievers in this high range of ability.

Three profiling analyses were performed to differentiate between underachieving and non-underachieving students; one was conducted for each of the identification methods in the personal, family, and social variables.

A univariate analysis of variance (ANOVA) of repeated measures and a multivariate analysis of variance (MANOVA) were performed in each analysis.

In the results of the ANOVA performed on the scores of subjects identified with the standardized difference method, Mauchly's test did not confirm sphericity for the DV matrix ($W = 0.001$; $\chi 2 = 1023.57$, df = 170, $p = 0.001$); therefore, the degrees of freedom for the within-subjects test were corrected using Epsilon correction values. Once these corrections had been made, the F ratio for the flatness test was significant ($F = 9.45$, $p = 0.001$), indicating that there were differences between the variables within each group. In the test for parallelism – interaction, variables by group indicated that the profiles were different across groups ($F = 37.80$, $p = 0.001$).

To analyze whether significant differences existed between the variable scores of underachieving and non-underachieving students, the level test was conducted; this showed that the variable means for each group were significantly different one another ($F = 40.82$, $p = 0.001$).

Since the univariate analysis did not fulfill the sphericity assumption, the results of the multivariate analysis were included. For within-subjects effects, the Wilks Lambda was significant ($\lambda = 0.42$, $F = 11.03$, $p = 0.001$). The interaction variables by group were also significant ($\lambda = 0.70$, $F = 3.35$, $p = 0.001$).

Figure 1 shows the profiles of the gifted underachieving students group and the gifted normally achieving students group.

A t-test for independent groups was performed to evaluate whether specific variables showed statistically significant differences between groups (the underachieving and non-underachieving students groups). **Table 2** shows the descriptive statistics (means and standard deviations), t statistics, and significance of differences (p) for each of the identification methods employed. The results showed significant differences in most of the personal, family, school, and social variables. Underachieving students obtained lower scores in elaboration and metacognition strategies, learning goals, academic self-efficacy, attitudes to teachers, goal values, self-regulation, general academic self-concept, general private/personal self-concept, and perception of parents' support compared to the non-underachieving students.

In the analysis of data obtained with the residual scores of the regression technique, again, Mauchly's sphericity test did not confirm sphericity for the DV matrix ($W = 0.002$; $\chi 2 = 1006.79$, df = 170, $p = 0.001$); therefore, the degrees of freedom for the within-subjects test were corrected using Epsilon correction values. After that, the F ratio for the flatness test was significant ($F = 2.97$, $p = 0.001$), indicating that there were differences between the variables within each group. More importantly, the test for parallelism – interaction variables by group indicated that the profiles were different across groups ($F = 3.64$, $p = 0.001$). The profiles of both groups are shown in **Figure 1B**.

The level test showed that the means of the motivational and attitudinal measures were significantly different in each group ($F = 10.07$, $p = 0.002$).

The results of the MANOVA indicated that regarding within-subjects effects, the Wilks Lambda was significant ($\lambda = 0.66$, $F = 4.06$, $p = 0.001$). The interaction variables by group were also significant ($\lambda = 0.72$, $F = 3.04$, $p = 0.001$).

To assess which variables presented statistically significant differences between the groups, a t-test for independent groups

TABLE 1 | Descriptive statistics of the high-ability underachieving and non-underachieving students identified with the three statistical methods.

	Method								
	Difference			Regression			Rasch		
	Frequency	Mean		Frequency	Mean		Frequency	Mean	
		IQ	Ach.		IQ	Ach.		IQ	Ach.
Underachieving	42 (25.6%)	129	6.87	18 (11.0%)	126	5.76	24 (14.6%)	125	6.10
Non-underachieving	122 (74.4%)	125	8.84	146 (89.0%)	126	8.48	140 (85.4%)	126	8.54
	164 (100%)			164 (100%)			164 (100%)		

Ach., academic achievement; IQ, intellectual quotient.

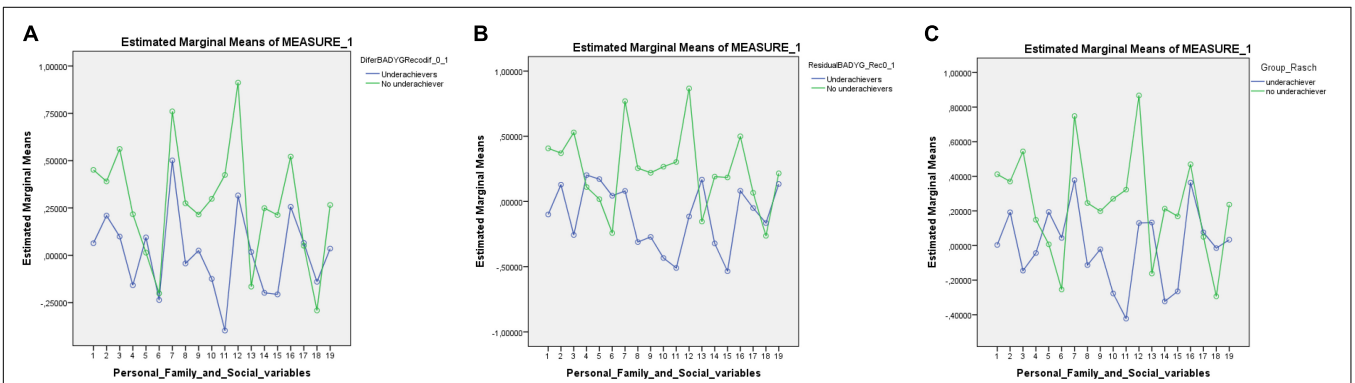

FIGURE 1 | Profiles of high-ability underachieving and non-underachieving students identified by the standardized difference **(A)**, residual **(B)**, and Rasch **(C)** methods in personal, family, and social variables.

was performed. The results of this analysis are shown in **Table 2**. The results showed differences in the same variables as in the standardized difference method, with the exception of learning goals, which showed no significant differences between groups.

The ANOVA performed on the data obtained from the subject identified by the Rasch method showed that Mauchly's sphericity test did not support sphericity (W = 0.002, $\chi 2$ = 1011.82, df = 170, p = 0.001); therefore, the degrees of freedom for the within-subjects test were corrected using Epsilon correction values. The F ratio for the flatness test was significant (F = 4.59, p = 0.001), indicating that there were differences between the different variables within each group. Further, on the test for parallelism – interaction, variables by group indicated that the profiles were different across groups (F = 3.32, p = 0.001). The profiles for both groups are shown in **Figure 1C**.

The level test also showed significant mean differences in the variables between groups (F = 6.07, p = 0.01).

The results of the MANOVA indicated that regarding within-subjects effects, the Wilks Lambda was significant (λ = 0.56, F = 6.33, p = 0.001). The interaction variables by group were also significant (λ = 0.72, F = 3.01, p = 0.001).

The t-test results presented in **Table 2** indicate that significant differences were found for the same variables as in the residual regression method, with the exception of that related to attitudes toward teacher. Underachieving students had lower scores in elaboration and metacognition strategies, academic self-efficacy, goal values, self-regulation, general academic self-concept, general private/personal self-concept, and perception of parents support compared to non-underachieving students.

Although the Box's M test did not show homogeneity of variance–covariance matrices in the MANOVA, the highest ratio of variance between groups did not exceed the 1:10 (Tabachnick and Fidell, 2007) in the analysis performed on the scores of subjects identified with the standardized difference method (1:6.45), residual regression method (1:6.17), or Rasch method (1:4.91).

Looking again at **Table 2**, it can be observed that in most cases, the differences obtained with either method occurred in the same variables. The exception was in learning goals, where the only differences between underachievers and non-underachievers occurred with the method of standardized differences and in the variable attitudes toward the teachers, in which differences between the students and the Rasch method do not occur.

DISCUSSION

The results allow us to respond to the research objectives, which were to examine the differences between underachieving and non-underachieving gifted students in individual, family, social, and school variables and compare these differences when different methods of identification of underachievement are used.

TABLE 2 | Descriptive statistics and mean differences between underachieving and non-underachieving high-ability students identified by the three methods.

Method	Simple standardized difference				Residuals of regression				Rasch model				
	Under $\bar{x}$ (SD)	Non-under $\bar{x}$ (SD)	*t*	*p*	Under $\bar{x}$ (SD)	Non-under $\bar{x}$ (SD)	*t*	*p*	Under $\bar{x}$ (SD)	Non-under $\bar{x}$ (SD)	*t*	*p*	No. of diff.
Variable													
1	0.06 (1.01)	0.45 (0.89)	−2.34	0.02	−0.09 (0.90)	0.40 (0.92)	−2.19	0.03	0.01 (0.84)	0.41 (0.94)	−1.99	0.04	3
2	0.20 (1.14)	0.39 (0.93)	−1.01	0.31	0.12 (1.06)	0.37 (0.98)	−0.97	0.33	0.19 (0.93)	0.36 (1.01)	−0.80	0.42	–
3	0.09 (1.16)	0.56 (0.97)	−2.52	0.01	−0.25 (1.18)	0.52 (0.99)	−3.10	0.01	−0.14 (1.07)	0.54 (1.01)	−3.07	0.01	3
4	−0.15 (0.99)	0.21 (1.05)	−2.01	0.04	0.20 (0.74)	0.11 (1.08)	0.46[a]	0.64	−0.04 (0.83)	0.14 (1.08)	−0.82	0.41	1
5	0.09 (0.94)	0.01 (1.11)	0.41	0.67	0.17 (0.96)	0.01 (1.08)	0.57	0.56	0.19 (0.99)	0.01 (1.08)	0.78	0.43	
6	−0.23 (1.31)	−0.20 (1.29)	−0.14	0.88	0.04 (1.02)	−0.24 (1.30)	0.88	0.38	0.04 (1.07)	−0.25 (1.33)	1.03	0.30	–
7	0.50 (0.83)	0.76 (0.73)	−1.96	0.05	0.08 (0.91)	0.76 (0.71)	−3.72	0.01	0.37 (0.79)	0.74 (0.75)	−2.20	0.02	3
8	−0.04 (0.95)	0.27 (0.82)	−2.06	0.04	−0.31 (1.02)	0.25 (0.83)	−2.65	0.01	−0.11 (0.98)	0.24 (0.84)	−1.88	0.06	2
9	0.02 (1.04)	0.21 (0.80)	−1.07[a]	0.28	−0.27 (1.08)	0.22 (0.82)	−1.86[a]	0.07	−0.02 (1.02)	0.19 (0.84)	−1.14	0.25	–
10	−0.12 (1.18)	0.29 (0.59)	−2.22[a]	0.03	−0.43 (1.40)	0.26 (0.66)	−2.08[a]	0.04	−0.27 (1.26)	0.26 (0.66)	−2.07[a]	0.04	3
11	−0.39 (1.07)	0.42 (0.79)	−4.54[a]	0.01	−0.50 (0.84)	0.30 (0.92)	−3.56	0.01	−0.42 (0.94)	0.32 (0.90)	−3.70	0.01	3
12	0.31 (0.94)	0.91 (0.59)	−3.85[a]	0.01	−0.11 (0.79)	0.86 (0.66)	−5.80	0.01	0.13 (0.82)	0.86 (0.67)	−4.13[a]	0.01	3
13	0.01 (1.26)	−0.16 (0.95)	0.98	0.32	0.16 (1.37)	−0.15 (0.99)	1.23	0.21	0.13 (1.23)	−0.16 (1.01)	1.28	0.20	–
14	−0.19 (0.95)	0.24 (0.86)	−2.80	0.01	−0.32 (0.91)	0.19 (0.89)	−2.28	0.02	−0.32 (1.04)	0.21 (0.86)	−2.71	0.01	3
15	−0.20 (1.12)	0.21 (0.89)	−2.44	0.01	−0.53 (1.20)	0.18 (0.91)	−3.02	0.01	−0.26 (1.16)	0.16 (0.92)	−2.03	0.04	3
16	0.25 (0.92)	0.52 (0.51)	−1.76	0.08	0.08 (1.09)	0.49 (0.56)	−1.58[a]	0.13	0.36 (1.02)	0.46 (0.56)	−0.49[a]	0.62	–
17	0.06 (0.84)	0.04 (0.90)	0.09	0.92	−0.05 (0.83)	0.06 (0.89)	−0.52	0.59	0.07 (0.79)	0.05 (0.90)	0.13	0.89	
18	−0.13 (0.85)	−0.29 (0.82)	1.01	0.31	−0.16 (0.86)	−0.26 (0.82)	0.47	0.63	−0.01 (0.93)	−0.29 (0.80)	1.52	0.13	
19	0.03 (1.04)	0.26 (1.13)	−1.16	0.24	0.13 (1.10)	0.21 (1.11)	−0.29	0.76	0.03 (1.12)	0.23 (1.11)	−0.82	0.41	–

Variables: 1, elaboration strategies; 2, personalization strategies; 3, metacognition strategies; 4, learning goals; 5, social reinforcement goals; 6, achievement goals; 7, academic self-efficacy; 8, attitude toward teacher; 9, attitude toward school; 10, goal values; 11, self-regulation; 12, general academic self-concept; 13, general social self-concept; 14, general private self-concept; 15, parent support; 16, expectations; 17, school relations; 18, time on homework; 19, popularity. [a]Equal variances not assumed.

First, the percentage of participants identified as underachieving differed significantly, depending on the method of identification. In this sense, although a higher number of underachieving students were expected to be identified by the Rasch method (H1), both the standardized difference method and the regression method identified a similar number of students. This discrepancy may be due to a minor level of differences between gifted students in comparison with students from other ability ranges. However, given the lack of generalization of this method, further studies should be developed to explore psychometric properties according to students' characteristics.

Although these results, which were obtained from among high-ability students, reveal the lack of consistency in the different operational definitions of underachievement, all three methods identified a significant percentage of underachieving students, similarly to other studies involving students with broader ability ranges (Phillipson, 2008; Veas et al., 2016a,b).

Second, the results showed statistically significant differences between underachieving and non-underachieving students in most of the variables studied, as is pointed out by recent revision studies on gifted underachievement (Siegle and McCoach, 2018; White et al., 2018).

Regarding learning strategies, these were used less by underachieving students, who reported minor use of elaborative and metacognitive strategies. These findings were comparable to those reported in studies on gifted underachieving students (Dowdall and Colangelo, 1982; McCoach and Siegle, 2003b; Colangelo et al., 2004), in which underachieving students showed decreases in these strategies. From this, we can conclude that learning strategies are a key variable to explain underachievement (Chiu et al., 2007; Yip, 2007).

With regard to motivation, the results showed that underachieving students reported lower scores in learning goals compared with non-underachieving students, whereas no differences in achievement goals or social reinforcement goals were shown. There are many studies showing lower levels of motivation in underachieving students (Schick and Phillipson, 2009; Dunlosky and Rawson, 2012; Preckel and Brunner, 2015).

High-ability underachieving students also showed worse academic self-perceptions, attitudes toward teachers, goal values, and motivation/self-regulation, as reported by McCoach and Siegle (2003a), who pointed out these variables in high-ability students with low achievement. Castejón et al. (2016) also found this in a sample with a broader range of ability.

With respect to self-concept, high-ability underachieving students showed lower general academic self-concepts and personal/private self-concepts. These results are similar to the studies by Preckel and Brunner (2015) and Rimm (2003). McCoach and Siegle (2003a,b), on the other hand, found lower general self-concepts but not lower academic self-concepts in gifted underachieving students. In the same way, McCoach and Siegle (2003a,b) found that underachieving students showed lower private/personal general self-concepts. In all of these works, underachieving students evidenced lower personal self-concepts.

In this case, the second hypotheses (H2a and H2b) are partially accepted, as underachieving gifted students showed higher scores on learning goals, but they did not score significantly higher on achievement goals and social reinforcement goals.

However, according to our hypotheses, underachieving students showed significantly higher scores than non-underachieving students in general social self-concept. Although the majority of the studies that analyze differences between gifted and non-gifted students in self-concept dimensions, gifted students showed significantly lower scores than the non-gifted ones in social self-concept (Zeidner and Shani-Zinovich, 2015). In this case, within a gifted sample, it has been shown that it is not a homogeneous group in this factor, and underachieving students showed considerably lower scores.

Differences in family factors also were found. High-ability underachieving students perceived lower parental support, although there were no significant differences in perceived parental expectations, relations of parents with the school, or reported time spent supporting homework compared to non-underachieving students. Parental expectations, parental support, and parent-school relationships seem to be good predictors of parental involvement and student achievement, as stated by some meta-analyses (Jeynes, 2005, 2012; Wilder, 2014). Also, higher time support is related to lower academic performance (Gonida and Cortina, 2014). Contrary to expectations, there were no significant differences in popularity between high-ability underachieving and non-underachieving students.

In sum, the profiles of the high-ability underachieving students showed minor use of elaboration and metacognitive strategies, less learning goal orientations, poor academic self-perceptions, minor attitudes toward teachers, minor self-regulation, lower academic and personal self-concepts, and lower perceptions of parent support in the educational process. In most cases, the differences obtained with any method used occurred in the same variables.

Knowing these characteristics is necessary for the design and implementation of programs aimed at reversing the low academic performance of high-ability underachieving students (Renzulli and Reis, 1997; Chan, 1999, 2005). Further, any educational intervention focused on reversing low academic achievement in high-ability underachieving students must focus simultaneously on these characteristics (Baum et al., 1995).

Taken together, these results showed high congruence between methods of establishing differences in the variables, despite their different operational definitions of underachievement. Regardless of the method employed, there were significant differences between underachieving and non-underachieving students in terms of individual and family characteristics; this was held true for the current study, which involved high-ability subjects, and in studies that included larger samples of participants with broader ranges of ability (Castejón et al., 2016). Therefore, the results obtained so far support the concept of underachievement and the characteristics of underachieving students, regardless of their capacity.

Considering the actiotope model of giftedness as a dynamic model, these results let us propose possible educational strategies to reverse underachievement. In the first place, although gifted students should have a clear intellectual potential, this capacity needs internal cognitive resources that resolve "how" to work with academic contents. In this area, learning strategies are crucial cognitive tools to be trained in from childhood. Thinking about how personal resources could be improved leads us to the second point, to create parenting-school communication bridges with similar patterns of interests and contexts. From the social educational capital perspective, many studies have concluded that student achievement is related more with intellectual stimulation in the home than to parental socioeconomic status (Woolley and Grogan-Kaylor, 2006).

Given these consistent results, it is clear that there is a need for constant interactions between family and teachers. Moreover, by knowing the parents' perspectives on the factors that support the development of giftedness in their children, it is possible for gifted students to gradually internalize a positive motivation and self-concept (Heller, 2010). At the same time, it is important to consider the access of high-quality education for gifted students from an early age (Vialle, 2017). Apart from classical enrichment programs, and although unexplored in gifted students, possible useful interventions can be those under the funds of knowledge approach (González et al., 2005), focused on having teachers learn about family knowledge and skill that they can use to plan learning activities that connect the curriculum to family skill.

Finally, some limitations may be addressed. First, the present work involved a relatively low number of high-ability students as participants, which could prevent the appearance of significant differences in some variables. For this reason, future studies with larger numbers of high-ability students are needed with adequate sampling procedures to ensure representativeness. Second, longitudinal analysis is also be needed to explore the measures' consistency at different time points. This would let us explore reciprocal relations among the variables.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The research meets ethical guidelines, including adherence to the legal requirements of the study country. The present research was approved by the Ethical Committee of the University of Alicante.

AUTHOR CONTRIBUTIONS

RG-C: quantitative methods and theoretical review of the study. AV: theoretical review of the study. PM: theoretical review of the study and review of the references. J-LC: quantitative methods.

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REVIEW
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Deliberate Practice and Proposed Limits on the Effects of Practice on the Acquisition of Expert Performance: Why the Original Definition Matters and Recommendations for Future Research

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Over 25 years ago Ericsson et al. (1993) published the results of their search for the most effective forms of training in music, a domain where knowledge of effective training has been accumulated over centuries. At music academies master teachers provide students individualized instruction and help them identify goals and methods for their practice sessions between meetings – this form of solitary practice was named *deliberate practice,* and its accumulated duration during development was found to distinguish groups with differing levels of attained music performance. In an influential meta-analysis Macnamara et al. (2014) identified studies that had collected estimates of practice accumulated during development and attained performance and reported that individual differences in deliberate practice accounted for only 14% of variance in performance. Their definition of "deliberate practice" differs significantly from the original definition of deliberate practice and will henceforth be referred to as *structured practice*. We explicate three criteria for reproducible performance and purposeful/deliberate practice and exclude all effect sizes considered by Macnamara et al. (2014) that were based on data not meeting these criteria. A reanalysis of the remaining effects estimated that accumulated duration of practice explained considerably more variance in performance (29 and 61% after attenuation correction). We also address the argument that the limited amount of variance explained by the duration of practice necessarily implies an important role of genetic factors, and we report that genetic effects have so far accounted for remarkably small amounts of variance – with exception of genetic influences of height and body size. The paper concludes with recommendations for how future research on purposeful and deliberate practice can go beyond recording only the duration of practice to measuring the quality of practice involving concentration, analysis, and problem solving to identify conditions for the most effective forms of training.

Keywords: deliberate practice, expert performance, mental representation, practice effects, heritability

INTRODUCTION

Since the publication of Ericsson, Krampe, and Tesch-Römer's article on "The Role of Deliberate Practice in the Acquisition of Expert Performance" in 1993, the concept of deliberate practice has received a lot of attention. In the fall of 2019, over 25 year later, Google Scholar reported over 10,000 citations of that article and over 35,000 articles containing the word combination "deliberate practice" from 1993 to date, compared to fewer than 500 cases before 1993. It is important to note that Ericsson et al. (1993) defined the term *deliberate practice* as the individualized solitary practice in classical instrumental music as directed by a qualified teacher. This type of practice requires that several different criteria are met. Some early investigators noticed that the conditions for deliberate practice were rarely met in sports (Starkes et al., 1996). More recently Baker et al. (2005, p. 65) argued that deliberate practice is "predicated on the concept that it is not simply training of any type, but the engagement in specific forms of practice, that is necessary for the attainment of expertise". Deliberate practice was presented (Ericsson et al., 1993) as the result of a search for evidence on optimal learning and improvement of performance. This research was an effort to explore if one could find examples in everyday life corresponding to the surprisingly large improvements in memory performance (over 1,000%) demonstrated by a college student after engaging in hundreds of hours of extended practice (Ericsson et al., 1980).

The domain of music has historically utilized individualized training of full-time students by teachers and has accumulated knowledge about effective training for several centuries. At an international music academy, the best violinists were compared to less accomplished expert violinists and were found to have engaged in more solitary practice during their musical development (Ericsson et al., 1993). Subsequent research documented that the increased amount of certain types of practice was correlated with higher levels of attained performance in a wide range of domains (Ericsson, 1996, 2003, 2007; Ericsson and Lehmann, 1996; Ericsson et al., 2018). These findings stimulated a number of journal editors to assign special issues that focus on discussions on the role of nature and nurture in the development of expertise in journals such as *International Journal of Sport Psychology* (Baker and Davids, 2007), *High Ability Studies* (Stoeger, 2007), and *Intelligence* (Detterman, 2014).

Over a decade after the original publication of the paper proposing deliberate practice, Gladwell (2008) published his very popular book *Outliers*, and he dedicated a whole chapter to the topic of the "10,000 h rule" and cited our paper (Ericsson et al., 1993) as the primary empirical evidence for the rule. In that chapter Gladwell (2008) proposed that a minimum of hours of practice was necessary and that this number was "the magic number for true expertise: ten thousand hours." Although our research showed that an extended period of training and practice was required for attaining international-level performance, there was no evidence for a magical number. In fact, to win international piano competitions the first author estimated that around 25,000 h would be more accurate (Ericsson, 2013). Even more significantly, Gladwell (2008) never mentioned the term "deliberate practice" in his book and only referred to practice in general. His discussed examples of individuals surpassing the 10,000 h boundary to world-class success explicitly included many types of practice activities that were violating the criteria for deliberate practice, such as public performances and work. As is often the case when ideas are popularized, they become simplified and lose their original meaning. The 10,000 h rule was interpreted as saying that unless one has engaged in an activity for 10,000 h one will not have been able to reach excellence and mastery. The more popular interpretation says "'10,000 h' succeeds as a meme because it tells people what they want to believe, that with enough practice, anyone can covet the skills of genius. It's not so much that people want to become world-class musicians or top physicists, but rather that they have the potential to become those things if they want to, by practicing enough" (Hacker news, 2017). The essence of the popular belief is that the critical factor determining one's attained performance is how long one has been practicing, which could be measured by the number of estimated hours that a given individual has practiced.

It is possible to assess the validity of this belief by conducting a meta-analysis of the correlation between the accumulated amount of practice and attained performance in a wide range of domains. Macnamara et al. (2014) conducted the first meta-analysis and they identified over 9,000 studies that matched keywords, such as "practice," "deliberate practice," and many other related terms. They also required that "the study report referred to at least one publication on deliberate practice by Ericsson and his colleagues" (p. 1610), and that the study report provided information on an accumulated amount of practice and a measure or index of performance. Studies meeting these criteria contributed the data for their meta-analysis. Macnamara et al. (2014) claimed their analysis would evaluate Ericsson et al. (1993) "influential deliberate-practice view of expert performance. This view holds that expert performance *largely reflects accumulated amount of deliberate practice*" (Macnamara et al., 2014, p. 1608, italics added). Out of the many studies identified they selected 88 studies which had measured "accumulated amount of one or more activities *interpretable* as deliberate practice" (p. 1611, italics added). They did not use the definition proposed in the original paper (Ericsson et al., 1993), but selected a more general description from the paper (the differences between definitions will be discussed in more detail later in this paper). They interpreted the definition to be as follows: "*deliberate practice*, which was defined as engagement in structured activities created specifically to improve performance in a domain" (Macnamara et al., 2014, p. 1608). Their meta-analysis concluded: "We found that deliberate practice explained 26% of the variance in performance for games, 21% for music, 18% for sports, 4% for education, and less than 1% for professions. We conclude that deliberate practice is important, but not as important as has been argued" (Macnamara et al., 2014, p. 1608). They claimed that their results estimated the relation between attained reproducibly superior performance and the accumulated amount of deliberate practice, but we disagree and will show that their definition of "deliberate practice" included a much broader set of activities, such as many types of domain-specific experiences and competitive events. Drawing on Macnamara et al. (2014, 2016) published claims about deliberate practice, many researchers

cited the results of this meta-analysis to show the limits of any type of practice in influencing performance. For example, some scientists studying sport cited those estimates in support for their claim that the remaining factors are "substantially heritable in nature" (Georgiades et al., 2017, p. 62), and thus, by inference, elite sport performance is primarily determined by individual differences in genes. In a recent review article Moreau et al. (2018) cited a meta-analysis of studies analyzed by Macnamara et al. (2014) but with a restriction to only studies of sports performance (Macnamara et al., 2016). This meta-analysis was cited to show that deliberate practice could not explain any statistically significant amount of the variance of individual differences "in performance among elite-level performers" (Moreau et al., 2018, p. 333). Similarly, Thomas and Lawrence (2018) reviewed expert performance across different professional domains and claimed that "deliberate practice fails to account for large proportions of variance in expertise" (p. 171).

These claims about the limitations of deliberate practice to influence attained levels of performance are based on Macnamara et al. (2014) meta-analysis. In this paper we will show that the definition adopted in the two meta-analyses (Macnamara et al., 2014, 2016) led to the inclusion of data on performance and practice that did not meet the criteria for deliberate practice and reproducible performance originally proposed by Ericsson et al. (1993). In the next section we will describe how the original definition of deliberate practice was generated, and in the immediately following section we will describe some problems that investigators had in identifying practice meeting all the criteria for deliberate practice in domains of expertise other than music and how this led to the need to distinguish and identify criteria for several different types of practice.

In the main body of this paper we will examine how our conceptions of deliberate practice and reproducible performance has implications for which studies in Macnamara et al. (2014, 2016) meta-analysis reflect deliberate and purposeful practice and therefore provide valid information about the relation between accumulated deliberate and purposeful practice and attained performance. We will sequentially apply three criteria to allow us to identify the small subset that can be agreed upon as representing valid information to be aggregated to estimate the relation between the accumulated estimated duration of deliberate and purposeful practice and attained reproducible performance. We will then calculate how this estimate can be corrected for attenuation for reliability and discuss issues related to restriction of range when the general hypothesis considered is "how much variance can practice account for when analyzing individual differences in performance." In addition, we discuss several issues regarding the strength of the relation between accumulated amount of deliberate and purposeful practice and attained reproducible performance, as well as why such aggregated estimates will never provide accurate estimates of the upper-bound for how much accumulated durations of high-quality practice can account for improvements of performance. The concluding sections propose how research on genetics and on detailed training histories can be combined to assess the relative role of these respective factors and their possible interactions in predicting the level of performance attained in the particular domain of expertise. In our final section, recommendations for future research on the development and acquisition of expert performance will be presented.

THE ORIGINAL DEFINITION OF DELIBERATE PRACTICE

The original stimulus for the work on deliberate practice came from the goal of finding effective training for attaining expert levels of performance in professional domains outside the laboratory. In the research collaboration with Bill Chase (Ericsson et al., 1980; Chase and Ericsson, 1981, 1982), college students with average performance on ability tests were shown to be able to dramatically increase their memory performance by engaging in several hundred hour-long laboratory sessions of practice distributed over more than a year. Consequently, Ralf Krampe, Clemens Tesch- Römer and the first author started our research by searching for "conditions for optimal learning and improvement of performance" (Ericsson et al., 1993, p. 367). This paper reviewed a century of laboratory studies of learning showed that performance was increased when participants "attend to the task and exert effort to improve their performance.... The subjects should receive immediate informative feedback and knowledge of results of their performance. The subjects should repeatedly perform the same or similar tasks" (p. 367). The review reported on a search for such activities with explicit goals and immediate feedback and identified a domain of expertise with centuries of successful production of expert performers, namely the training of instrumental musicians. Consequently, this paper examined the daily activities of music students attending an internationally renowned music academy. It was assumed that the select students admitted to the music academy were highly motivated to improve their performance to prepare for their professional careers and thus able and willing to "attend to the task and exert effort to improve their performance" (p. 367). There were only two types of activities that focused on explicit goals of improving aspects of individual performance with established practice activities that offered immediate feedback and opportunities for repetition after reflection. The first type of activity involved individual students' lessons with their teacher, but those lessons are typically restricted to around only 1 h per week. It was observed, however, that the teacher influenced and guided practice activities beyond the lesson and "the teacher designs practice activities that the individual can engage between meetings with the teacher. We call these practice activities *deliberate practice*" (Ericsson et al., 1993, p. 368). More specifically, "[T]to assure effective learning, subjects ideally should be given explicit instructions about the best method and be supervised by a teacher to allow individualized diagnosis of errors, informative feedback, and remedial part training. The instructor has to organize the sequence of appropriate training tasks and monitor improvement to decide when transitions to more complex and challenging tasks are appropriate" (Ericsson et al., 1993, p. 367). This paper pointed out that the activity of deliberate-practice is a particularly interesting locus of individual differences in the amount of practice because the music students can control when and for

how long they engage in this type of practice. Consequently, this paper hypothesized that students who consistently engaged in more hours of this type of "practice alone" per week would be predicted to improve their music performance significantly more.

Deliberate practice differs qualitatively from most other forms of practice. The first criterion is that the practice involves individualized training of a trainee by a well-qualified teacher. This teacher can assess which aspects a particular trainee would be able to improve during the time until the next meeting and is able to recommend practice techniques with established effectiveness. The second criterion is that the teacher must be able to communicate the goal to be achieved by the trainee and that the trainee can internally represent this goal during practice. It is challenging for the trainees to be able to mentally represent a goal for a level of performance that the trainee is initially unable to attain. For example, to attain successful mastery of a music piece (see **Figure 1**) the trainees need to be able to mentally represent the desired sound of the piece of music (top box in **Figure 1**) in order to be able to generate controlled attempts with their instruments that gradually approach this goal (left lower box). The third criterion is that the teacher can describe a practice activity to attain the identified goal for performance and that this activity allows the trainee to get immediate feedback on a given attempt. For example, a musician would be able to listen to the sound of their produced attempt (right lower box) and be able to notice differences between the sound of their desired goal and of their current attempt and then make the differences targets for generating a new and better attempt after opportunities for reflection and problem solving. The fourth criterion is that the trainee is able to make repeated revised attempts that gradually approach the desired goal performance.

There is an additional feedback cycle that occurs when trainees return to their teacher for their lessons and demonstrate the performance that they had worked on throughout the week. The students will get feedback on how well they attained the assigned goals from the previous meeting and the teacher can help the trainees to refine their mental representations so they can reliably notice differences that have not yet been successfully addressed. Once current practice goals have been attained, the music teacher identifies new goals and associated valid practice activities to allow a particular student to keep improving their performance with additional deliberate practice. The deliberate practice framework argues that expert performers continue to strive to attain more refined mental representations, which provide increased ability to control performance. This is in direct contrast to traditional theories of acquisition of everyday skills (Fitts and Posner, 1967), where individuals try to automate their behavior within weeks or months to minimize effort. In support of the expert performance account, expert performers are able to verbalize their thoughts during planning and evaluation of their performance when they are asked to "think aloud" (Ericsson, 2018a) and are able to recall much more relevant information encountered during a brief exposure to a challenging situation than their less accomplished peers (Ericsson, 2018b).

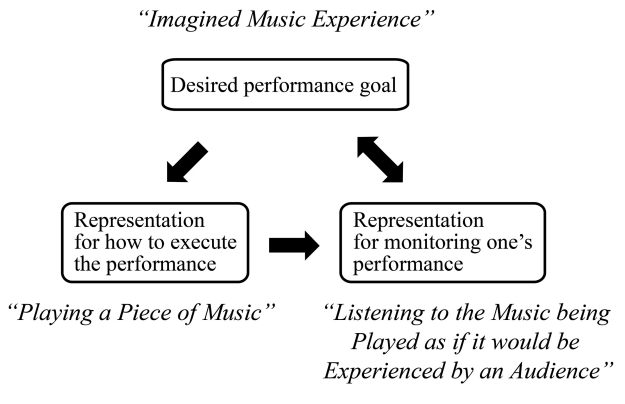

FIGURE 1 | Three types of systems of mental representations that mediate expert music performance and its continued improvement during deliberate practice. Adapted from Figure 6 in Ericsson (1998).

CHALLENGES IN EFFORTS TO FIND DELIBERATE PRACTICE IN DOMAINS OTHER THAN MUSIC

As mentioned earlier, researchers in different domains reported difficulties finding practice activities that exactly matched the individualized one-on-one training in music. For example, Starkes et al. (1996) searched for practice activities in different sports that were rated as highly related to improvement, requiring a high level of concentration and would not be enjoyable, but were not able to find activities that met all three criteria. Other pioneering investigators, such as Charness et al. (1996) focused on a single particular domain, namely chess, and searched for a domain-specific practice activities such as "serious analysis of positions alone (chess books, magazines, databases, postal chess, etc.)" (p. 75) that they referred to as "serious practice alone" or deliberate practice alternatively. They also gathered information on the amount of time that the chess players had spent with a coach and found that coached players attained higher chess ratings, but also that coached players spent more time on serious practice alone so there was not an independent benefit of amount of coaching in that sample. However, Ericsson and Charness (1994) had stated clearly that "self-directed study has most of the characteristics of deliberate practice, but it is probably not as effective as individualized study guided by a skilled teacher" (p. 739). Other researchers started exploring less well-defined domains of expertise. Dunn and Shriner (1999) interviewed teachers to identify "deliberate practice as those activities which are highly relevant to improving performance and require significant personal effort to initiate and maintain" (p. 632) within the domain of teaching. They had teachers rate different types of practice activities and identified practice activities that had high ratings of relevance for self-improvement as teachers, perceived effort and frequency of occurrence, such as "preparing materials needed for instructional activities" (p. 636). In a second study they had expert teachers, defined as someone with over 10 years of experience, keep a diary of their different activities during a week. This study is an interesting effort to identify activities, referred to as deliberate practice,

that some expert teachers might engage in to keep improving their teaching performance throughout their career. However, there was no objective measurement of teaching performance, nor any identification of specific goals for improving aspects of performance along with effective practice tasks and no supervision of training by a skilled teacher. In several domains of expertise, researchers have become interested in the idea of identifying practice activities that experts would have engaged in to reach a superior level of objective performance. At the same time, it is essential to distinguish the search for such activities from the original definition of deliberate practice (Ericsson et al., 1993), which referred to individualized training designed by a teacher in a domain with a well-developed knowledge about effective methods for improving aspects of performance.

When Ericsson et al. (1993) defined deliberate practice, they created a problem by only introducing a single new concept. There are a range of practice activities that do not meet all the criteria for deliberate practice but are still associated with performance gains. More recently Ericsson and Pool (2016) addressed this conceptual confusion and proposed the term *purposeful practice* for individualized practice activities which the trainee engages in to improve their performance but without the benefit of a teacher with extensive knowledge of effective methods for practice. This type of practice is well illustrated by the serious practice alone in chess (Charness et al., 1996), in SCRABBLE (Moxley et al., 2019), in darts (Duffy et al., 2004), in bowling (Harris, 2008) and many individual sports, such as running (Young and Salmela, 2010). In addition, Ericsson and Pool (2016) proposed the term *naïve practice*, for practice involving merely engaging in domain-relevant activities, such as playing games with friends and others in tennis, golf, and soccer. In the case of people working in various professions, naïve practice would involve simply executing the job in response to demands evolving normally by external factors.

ASSESSING THE MODIFIABILITY OF EXPERT PERFORMANCE IN RESPONSE TO DELIBERATE PRACTICE

It is challenging to attempt to measure the maximal degree to which practice can influence the level of attained performance, but it is possible to identify several necessary steps. The first step would involve describing and clearly defining the type of practice that shall be examined. This is of crucial importance for studies of deliberate practice, which was defined to be a very different type of practice compared to the typical engagement in activities in the domain. The second step involves explicating how one can describe and measure individual differences in the amount and quality of practice activities accumulated during an individual's prior development in the domain. A related issue concerns the possibility of creating indices that would quantify some of these differences that would allow one to relate individual differences in aspects of accumulated practice to attained performance. The third step involves the assessment of the relations between these indices of practice and the level of attained performance. In a subsequent section we will discuss how the relations between accumulated practice and attained performance, as well as other types of evidence, provide information about the limits of practice to improve performance.

Differences in the Two Definitions of Deliberate Practice by Ericsson et al. (1993) and Macnamara et al. (2014, 2016)

Earlier we described how different researchers attempted to identify deliberate practice in domains other than music. The most general idea, which was stimulated by our work on deliberate practice, led to the search for activities that motivated individuals engage in with the explicit goal of attempting to improve their reproducibly superior performance in some domain of expertise. Consistent with their search for deliberate practice, Macnamara et al. (2014, p. 1608, italics added) introduced their definition of "deliberate practice, which Ericsson et al. *defined* as engagement in structured activities created specifically to improve performance in a domain." Hambrick et al. (2014) similarly included the emphasis on activities that have been specially designed to improve the current level of performance. There is no disagreement that the goal of improving performance is one characteristic of deliberate practice, and Ericsson et al. (1993) even wrote that "deliberate practice is a highly structured activity, the explicit goal of which is to improve performance" (p. 368). This sentence was, however, not a definition of deliberate practice any more than the true statement that "a dog is an animal" would imply the inference that "all animals are dogs." To avoid confusion between our original definition of deliberate practice and the definition of deliberate practice presented by Macnamara, Hambrick, and their colleagues, we will refer to their definition as *structured practice*, which is consistent with a terminology proposed by Hüttermann et al. (2014).

Macnamara et al. (2014) definition of structured practice is very broad and would include a number of practice activities designed by teachers, students, groups and individuals for the purpose of improving. There is much less of a problem for Hambrick et al. (2014) because they restricted their meta-analysis to studies from only two domains of expertise, namely chess and music, where a couple of the pioneering studies proposed well-documented training activities. The definition of structured practice has direct consequences for the inclusion of data sets in Macnamara et al. (2014) meta-analysis. For example, some of the included studies examined nurse education (Snelling et al., 2010) and measured the number of hours spent at lectures and seminars as a measure of accumulated practice. More generally, many other included studies used self-reports of hours of studying as the only measure of hours of accumulated structured practice. These studies met Macnamara et al. (2014) criteria for inclusion because they all cited the same paper, where the first author was a co-author. In this paper, Plant et al. (2005) proposed that studying was not deliberate practice but stated in the title that there were "Implications of Deliberate Practice for Academic Performance" (p. 96). The whole paper was dedicated to a proposal "that distinctions between deliberate practice and other types of practice can be

applied to studying and that this distinction can, at least in part, explain why measures combining all types of study activities in the school system are not valid predictors of grades" (p. 99). Further evidence that including these papers on education and studying was not appropriate for an evaluation of deliberate practice is apparent by finding that nearly all of these studies only cited the Plant et al. (2005) study and did not even mention the term deliberate practice in the text of their articles. More generally, the practice activities involved in students' study of material in a single course cannot be isolated from their prior learning for over a decade in the school system, and additionally the structure of these activities are not sufficiently well understood to allow us to categorize this type of practice in a meaningful manner (Plant et al., 2005). Their results will not be considered further in this paper. Other studies of team sports collected number of hours engaged in organized activities for teams. For example, Helsen et al. (1998) studied soccer players' team practice that focused on games, tactics, technical skills and individual activities, such as running and weight training. When teams do training in groups, it is often not possible to individualize the training for each player. It is important to point out that organized team training may be quite effective in improving performance, but it does not meet all the criteria for deliberate practice.

The estimates used by Macnamara et al. (2014) consistently aggregated qualitatively different types of activities. For example, Baker et al. (2003) reported estimated amount of time spent in different activities for state and international-level athletes. Macnamara et al. aggregated the differences across all activities even though for some of the included activities, such as number of hours watching their sport on television, the state-level athletes spent nearly twice as many hours than the international level athletes. In other activities, such as hours of individual instruction with a coach, the international-level athletes report spending eight times as many hours as the state-level athletes. Similarly, Macnamara et al. (2014) aggregated correlations of hours of practicing alone and with others into a single estimate for the players of bowling in the study by Harris (2008).

Rather than simply criticizing the inclusion of effect sizes from these studies in these meta-analyses, we will propose how the studies could be re-analyzed in a manner that shows how these effect sizes, or at least some of the effect sizes, can provide information relevant to our research on aspects of deliberate practice. We will organize the effects with practice activities according to the three types of practice distinguished by Ericsson and Pool (2016), namely deliberate, purposeful and naïve practice as well as structured practice as proposed by Hüttermann et al. (2014).

Deliberate Practice

When we examined any practice activities reported in all the studies included in the meta-analyses, we found that very few of them met all the criteria for our definition of deliberate practice. Only a small minority described teachers/coaches assessing the individual performance of trainees and then recommending particular practice activities with immediate feedback.

Purposeful Practice

We found a considerably larger number of practice activities where trainees were engaging in solitary practice with the goal of improving particular aspects of performance without the regular access to individualized evaluation and guidance by a particular coach or teacher. This type of solitary practice is hardly ever completely independent of teachers and their knowledge about effective training. It is likely that these individuals had occasional meetings with a coach, discussions with more advanced athletes within the same sporting event, or reading books describing appropriate practice activities. Although individuals practice by themselves, some of them will know about practice activities with immediate feedback on their performance, such as interval training and training with weights, and thus engage in reasonably effective practice even without having a coach monitor and guide the detailed goals for their practice. To deal with this problem, we will be conservative and classify solitary practice activities as purposeful practice when these activities are not conducted with regular individual meetings and guidance from a particular teacher or coach. In addition, we excluded estimates of practice where it was not possible to determine how much of the time was spent in practice activities meeting the criteria for purposeful practice.

Structured Practice

This type of practice activity is best exemplified by the structured practice activity guided by coaches of teams or teachers of groups of students. That is, trainees engage in group activities designed by a coach or teacher, and these activities are not individualized and tailored to their current level of skill and opportunities to improve specific aspects of their current performance. Many of the practice estimates extracted from the included sports studies would be most appropriately classified as involving structured practice.

Naïve Practice

In the description of the characteristics of deliberate practice Ericsson et al. (1993) explicitly contrasted it to work and play activities, which both are motivated by other factors than the goal of improving a particular aspect of performance. The primary problem with many estimates of hours of engagement in practice activities is that the included practice activities are so broad that they most certainly include a considerable proportion of naïve practice. For example, organized practice for teams involve playing practice games between different groups of athletes participating in the team practice. In other cases, the researchers asked their participants, such as SCRABBLE players (Halpern and Wai, 2007), to give a single estimate for how much time they played and practiced per week. Some of the investigators collected estimates for how much time participants spent playing games as well as the amount time spent in team practice, which allowed them to assess the relative impact of participating in these different types of practice activities, but many did not.

Quantification of the Amount and Quality of Practice Accumulated During the Entire Period of Development

It is challenging to recall and estimate the practice activities that expert performers have engaged in during their development of performance to an elite level. In most domains of expertise the development of elite performance may span a period of 5–30 years, and elite performers often attain the highest performance of their careers sometime between ages 15 and 40 (Ericsson and Lehmann, 1996; Haugen et al., 2018). Consequently, performers competing at the international level- have often accumulated between 3,000 and 40,000 h of engagement in domain-specific activities before they reach their highest level of performance (Baker and Young, 2014). The amount, quality, and specific type of practice activities will change dramatically from the time a child first engages in a domain until they reach the highest levels of performance. Ericsson et al. (1993) found that music practice is frequently organized on a weekly schedule, where the trainee meets with the teacher once a week and then practices at a regular time each weekday. With increased skill the trainee gradually increases the duration of their daily practice time from about 15–20 min a day to 4–5 h at the music academy. The high degree of organization of practice makes it possible for musicians to give reasonable estimates of their weekly amount of practice for each year of their development. Ericsson et al. (1993) explicitly focused on music students who were working full-time on improving their performance as their primary goal, and in a subsequent study Krampe and Ericsson (1996) extended their work to study amateur and professional pianists of ages between 52 and 68 years old. They found that time taken for solitary practice decreased after graduation from the music academy due to professional obligations involving public music performances and giving music lessons to music students, as is illustrated in **Figure 2**.

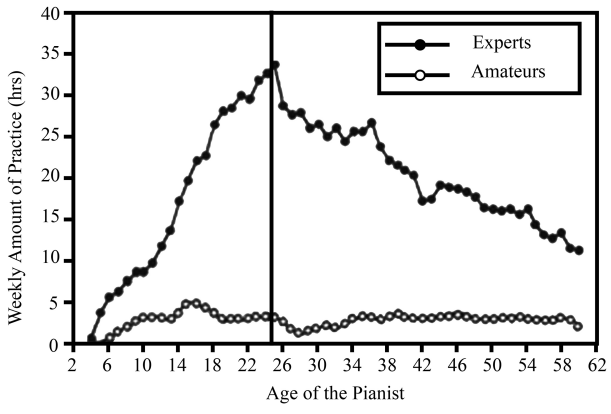

FIGURE 2 | Pianists' retrospective estimates of their weekly practice as a function of age. Data in the left panel are aggregated for young and older pianists. Data points above the minimum ages (20 for the young pianists and 52 for the older pianists) include at least 50% of the participants in each group (reproduced with permission of Figure 7 in Krampe and Ericsson, 1996).

Krampe and Ericsson (1996) found that the older expert pianists, when they kept practicing around 10–15 h per week, were able to match the performance of the young expert pianists on tasks that were representative of music performance. The average number of hours of accumulated practice alone for the older expert pianists was 57,739 *(SD* = 20,159) compared to only 17,927 h *(SD* = 6,615) for the young experts (Krampe, 1994). In spite of having accumulated around 6 standard deviations more hours of practice than the young experts, the older experts' performance was not superior. It was clear that the practice engaged in after graduation from the academy and the start of their professional career did not allow them to keep trying to improve their performance beyond its current level under the supervision of a teacher. Much of that practice focused on merely maintaining their already acquired performance, and Krampe and Ericsson (1996) referred to this practice as "maintenance practice." They found that rather than using the accumulated practice over their entire career, a measure of their more recent practice activity was a better predictor of their current level of performance. If a musician stops playing music for several years it is well-known that he or she cannot return to playing their instrument at a high level of performance without first engaging in a lengthy period of practice. Krampe and Ericsson (1996) found that the accumulated amount of solitary practice during the last 10 years was the measure that best predicted individual differences in the participants' performance on a range of experimental tasks, including when the analyses were restricted to the older and younger expert pianists. Similarly, Charness et al. (1996) noted that the current chess rating of older chess players was particularly influenced by their recent level of practice and was less well predicted by accumulated practice across their career when the predictability was compared to young chess players. We believe that the amount of accumulated practice necessary to reach the level of chess master estimated by Gobet and Campitelli (2007) is influenced by these issues. Gobet and Campitelli reported that the number of accumulated hours of solitary practice ranged from 1,612 to 14,196 to reach the level of chess master – a level corresponding to about the top 1% of the tournament players in a given country. We think that part of the variability in those numbers is likely influenced by whether the players remained fully committed to improving their chess skill throughout their career or whether they experienced periods of less intensive chess study where they play socially and only occasionally engage in solitary study. Similarly, Platz et al. (2014) noticed that Kopiez and Lee (2008) reported estimates for the accumulated number of hours of sight-reading music for both the period up to age 18 and also for the participants' entire life. Platz et al. (2014) recommended using the first estimate, as this estimate is not confounded by increases due to age without documented efforts to improve. Although the correlation with sight-reading performance was larger for this estimate, Macnamara et al. (2014) selected the life-long estimates with a lower correlation with performance. It is essential that future studies differentiate the periods when individuals are fully committed to reaching their highest levels from those periods when they are primarily engaging in practice to maintain their performance or periods when they stop engaging in the domain.

The problem of returning to one's earlier level of expert performance after a period of inactivity has been examined in the domain of crossword solving (Moxley et al., 2015) and in the domain of exceptional memory (Yoon et al., 2018). It should be possible in future research to elicit the goals for the solitary practice activities during different periods of an individual's life in order to allow the identification and analysis of the periods of purposeful practice as distinct from maintenance practice. The quality of the practice is more difficult to assess than the quantity. There is now research showing that the act of practice by oneself is not necessarily effective learning and thus would not lead to improvements in attained music performance. The solitary practice of many beginning music students does not involve goal-directed efforts to change (improve) their performance. Video recording of solitary practice sessions of children between 7 and 9 years of age showed that these children were not able to recognize mistakes and they simply played through the assigned music piece a few times, essentially without any improvements (McPherson and Renwick, 2001). The individuals' motivation to improve makes a big difference, and Evans and McPherson (2014) found a significant correlation between the amount of practice and the attained performance only for children who reported wanting to master their instrument. In a large-scale survey of several thousand young (age 6–19) musicians Hallam et al. (2012) found that with an increased level of attained music performance (assessed by objective tests) musicians practiced for more time, used more effective practice strategies and relied on the use of a metronome and tape recordings of their music practice and public performance.

There is another issue related to measuring only the duration of training. For example, when athletes develop strength and power they engage in a small number of trials of near-maximal effort. This type of practice can only be executed for short duration until muscular fatigue sets in. As a consequence, researchers have found that in sports requiring sprinting and explosive power for short periods there is a more important effect of very high intensity compared to the duration of sessions with purposeful practice and attained performance (MacInnis and Gibala, 2017). More generally, there are many sporting events where it is more important to generate maximal intensity for short periods of time, which can be monitored with physiological measures, such as heart rate, rather than increasing the duration of practice with a lower intensity (Mujika, 2010). In those cases, individuals can benefit by engaging in these activities more frequently during the week rather than extend the duration of individual sessions.

Finally, when expert performers are interviewed many years or even decades later about their practice during their entire development, they likely have difficulties recalling individual sessions and are forced to estimate and infer the number of hours of engagement in domain-specific activities based on their daily schedules. In many domains, individuals engage in organized training activities in team sports and other sports directed by coaches and teachers. In some domains, individuals establish daily schedules when they have plans to engage in practice every weekday for a certain amount of time, but they would occasionally need to change their plans to accommodate the need to seek a doctor, a dentist, or other sorts of interruptions to training schedules. This pattern was observed for the musicians at the music academy by Ericsson et al. (1993). These musicians estimated their typical weekly practice alone by multiplying their daily predicted practice time. These estimates correlated [$r(28) = 0.74$] with the time for this type of practice derived from their daily diaries filled out each day for a subsequent week. Interestingly, the musicians also estimated their weekly time for leisure, but these estimates were not significantly correlated [$r(28) = 0.082$] with the time for leisure derived from diaries.

One of the most ambitious attempts to correlate durations based on weekly diaries and estimates of weekly engagement was conducted in chess by de Bruin et al. (2008). They instructed their chess players to collect weekly diaries for three different weeks across the year. The diary data was converted to weekly estimates of serious chess study and was found to correlate [$r(34) = 0.60$] with the weekly estimate given for the current year. These findings suggest that the musicians and chess players were able to estimate the number of weekly hours of practice for the current year with correlations between 0.60 and 0.75.

Consistent with a distinction between practice and play, Hopwood (2015) found a reasonable reliability for purposeful practice in her review of recall of practice activities in sports, but substantially lower reliability for estimates of informal sporting activities. Ward et al. (2007) asked a subset of their participants to estimate their practice per year on two occasions. They found high reliability for estimates only for the most recent 5 years, but estimates for practice at longer intervals were not significantly correlated. More valid measures of error in estimation has been found for comparing athletes' estimated hours of practice with estimates given by their parents. Baker et al. (2003) found a correlation of $r = 0.59$ ($p < 0.05$) between the estimates of athletes and their parents. There have not been any studies that have collected concurrent diary data on weekly practice for aspiring experts throughout their entire development. The findings suggest reliabilities in the 0.6–0.8 range for the last year or two. It is plausible that the reliability and accuracy of estimates of weekly practice for as much as 15–20 years earlier will be considerably lower. A reasonable estimate of the reliability of these practice estimates would therefore be 0.6, which will later be used for correcting the correlations for attenuation. There are other methodological differences that will influence the reliability and validity of estimates of practice. In the original study Ericsson et al. (1993) asked participants to estimate how much practice alone that they had engaged in for each year since they started playing a music instrument. This study and others using a similar methodology show that the engagement in practice changes dramatically over an individual's career in the domain.

There are a number of studies that have not collected detailed information about participant's practice during their entire careers. For example, Howard (2012) asked his participants responding to an internet survey on chess to give only two estimates of their weekly estimate for studying chess. One estimate was the average weekly study in the past year and the second question was: "How many hours per week on average have you studied chess since taking up the game seriously?" (Howard, 2012, p. 362). It would have been very difficult to give

an accurate answer to that question when the engagement has varied substantially over the preceding decades, as illustrated by the professional musicians whose weekly average ranged between 3 and 32 h per week during different stages of their careers as shown in **Figure 2**. The average age of Howard's participants was a little younger than that of the musicians, but the mean age was still 35 years old, and Howard (2012) provided no evidence that his participants could accurately estimate their average weekly engagement by a single number. Consequently, we will not include Howard (2012) data on practice in our meta-analysis.

More generally, the detailed nature and structure of the engagement in practice activities will be very difficult to recall accurately in detail many years later. These issues should be less problematic for practice activities meeting the criteria for deliberate practice in domains with an established curriculum that prescribes a particular progression of mastery. In these domains a teacher will guide the student to engage in deliberate practice during the entire development. As long as the teacher is skilled in assessing improvable aspects of the performance of a trainee and is able to prescribe effective training, we can assume that the recommended practice activities will be effective if the trainee follows the teacher's instruction and engages in the practice activities with full concentration.

Assessment of the Correlation Between Indices of Estimated Amount of Accumulated Purposeful and Deliberate Practice and Attained Reproducibly Superior Performance

In the previous sections we have discussed how studies collecting data on diverse types of performance measures and practice activities were included in Macnamara et al. (2014) meta-analysis. In this section we will attempt to specify explicit criteria for a subset of effect sizes included in their meta-analysis that can be included in a meta-analysis of the relation between accumulated purposeful and deliberate practice and the attainment of reproducibly superior performance in a domain of expertise. In our review we will be very conservative, and some of these effects could potentially have met our criteria if the investigators had included more information and reported information about different practice activities. First, the measures of performance used by studies included in the Macnamara et al. (2014) meta-analysis will be examined to find those that meet the first criterion that their dependent variable measured reproducibly superior performance in a recognized domain of expertise (see **Figure 3**).

Identification of Studies Measuring Reproducibly Superior Performance in Domain of Expertise

In an earlier section we discussed the problems with most of the studies on education included in Macnamara et al. (2014) meta-analysis. These studies measured performance by one or more tests in a course or by the students' grade in the course. These measures are not acceptable as measures of reproducible performance in a recognized domain of expertise. When teachers assign grades in a course the grades are nearly always subjective judgments rather than an objective measurement of performance. Similarly, Macnamara et al. (2014) included effects from other studies where the performance variable consisted of ratings of athletes, musicians (Ruthsatz et al., 2008), and professionals (Sonnentag and Kleine, 2000). For example, Hendry (2012) and Memmert et al. (2010) relied on coach-generated ratings for assessing the performance of their players. There are clear problems with the validity of subjective ratings by a single person, especially if that person is responsible for deciding how much a given player will play during matches and other consequential decisions with regard to the players' training. More generally, it is not clear how one can assess the reliability and, in particular, validity of those ratings of a given individual or even a group of individuals. It is possible and even likely that different coaches

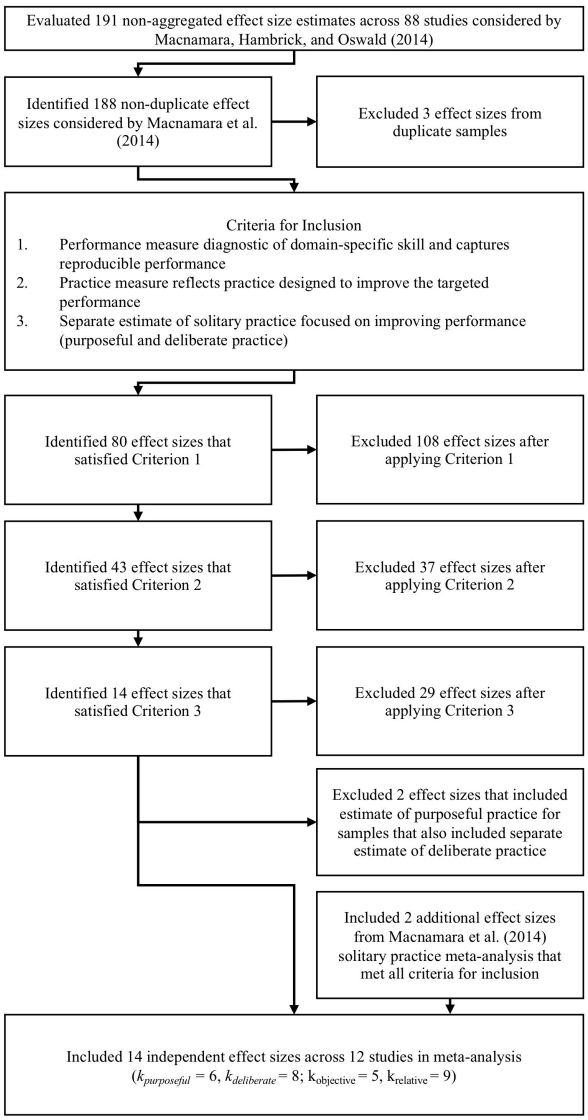

FIGURE 3 | Flow diagram of applying revised inclusionary criteria to estimates of the effects of deliberate practice on performance considered by Macnamara et al. (2014).

with similar, yet independent, knowledge of players would have given different ratings. In addition, it is essentially impossible to study athletes' development of performance if we cannot directly compare ratings of different judges. The problem of comparisons is particularly salient if we want to compare performance across historical time, such as the present time versus 100 years ago, or across different countries, such as China and Sweden. Ratings are based on relative judgments of abilities and performance whereas other domains of expertise rely on measurements of absolute objective performance, such as time to run 100 m, number of strokes to complete a golf course, and the results of tournaments (Ericsson, 1996). In domains with absolute measurements it is possible to describe individuals' performance by their level of competition, which would be primarily at the local, regional, state, national, and international levels. In that case there is a very close relation between the level of competition (a relative measure of performance) and the average performance of participants at the same level. In team sports, athletes' performance is often inferred from the level of competition of their respective team. In those cases, it is less clear how differences between individual athletes in teams competing at different levels correspond to differences in absolute performance, which may depend on individual differences among players on the same team, such as the playing position within a team. In our meta-analysis we will examine the potential effects of the distinction between relative and absolute performance by including it as a moderator.

Some of the studies included in in Macnamara et al. (2014) meta-analysis failed to provide evidence for a reproducible superiority, such as Law et al. (2007), where only the performance at an Olympic competition was cited as evidence for the superiority of the Greek team of rhythmic gymnasts over the Canadian team. This is a case where the authors of that study could have been able to report evidence on reproducibility of the superior performance of the Greek team across many competitions in a season, but they did not. Our review assessed whether all studies and their associated effect sizes in Macnamara et al. (2014) meta-analysis met Criterion 1, which required that the dependent variable had to measure reproducibly superior performance that qualified as a measure of expertise in the associated domain.

Identification of Studies Where Practice Is Designed to Improve the Targeted Performance

According to the deliberate practice framework, goals for a desired level of performance should drive the design of training and practice to help trainees to reach that performance. Studies of practice within the expert-performance approach would therefore meet Criterion 2 and measure duration of practice activities that are motivated by and designed to attain a higher level of the targeted performance (see Criterion 1). This requirement would seem obvious based on the large body of evidence on the specificity of training effects (Reilly et al., 2009).

In some domains, such as music, it has been challenging to find measures of musicians' ability to perform memorized music that can be administered easily and repeatedly during the year, in contrast to the use of juries at music competitions. Consequently, researchers have collected data on music-related tests involving sight reading, where a musician is asked to play an unfamiliar piece of music without opportunity to practice it. Sight reading is a very important activity for professional accompanists, but most music training focuses on helping musicians study a piece of music and then often memorize it. When ready, the musician would perform the piece of music with an orchestra for a large public audience. Macnamara et al. (2014) includes datasets that correlate the amount of deliberate practice toward becoming a soloist with the performance on tests of sight reading. Lehmann and Ericsson (1996) found that accumulated hours of deliberate practice was not significantly correlated with sight reading performance [$r(14) = 0.32$, $p > 0.05$], whereas the hours of accompanying performance was significantly correlated with this type of performance [$r(14) = 0.630$, $p < 0.01$]. In fact, when sight reading repertoire was included in the regression equation around 56% of the variance in sight reading performance was explained. Consequently, we will exclude effect sizes from studies relating amount of deliberate practice to performance on laboratory tasks, like sight reading tests, that do not explicitly capture the skilled performance that the individuals are training to attain. Platz et al. (2014) conducted a meta-analysis of a wide range of estimates of accumulated experience as well as estimates of accumulated deliberate practice on different measures of performance on sight-reading tests, and performance on laboratory tasks. Although the majority of the included studies measured accumulated experience, such as number of sight-reading performances, the aggregate relation between accumulated experience was impressive with a corrected correlation of $r = 0.61$ accounting for 36% of the variance in performance.

There are several other studies included in the meta-analysis where the accumulated practice estimates have been related to available performance variables without first demonstrating that the practice was directed toward improving each of those particular performance variables. For example, the accumulated practice estimates for the soccer referees in a study by Catteeuw et al. (2009) included many types of activities in their practice estimates. These researchers explicitly remarked that the hours of practice mostly were not relevant to improve skills related to accurate calls during games and tested scenarios. They recommended a search for practice activities that could include "additional decision-making experience outside match-play" (p. 1134).

In our review we examined all effects included in Macnamara et al. (2014) meta-analysis that had met Criterion 1, and assessed if the practice measure reflected practice directed toward improving target performance and that the estimate of accumulated practice accurately represented the sum of time spent engaging in practice activities that are directed toward improving the target performance (Criterion 2, see **Figure 3**).

Identification of Studies Where Estimates of Accumulated Practice Meets the Criteria for Measuring Solitary Practice Focused on Improving Performance (Purposeful and Deliberate Practice)

A common type of practice activity in many domains involves training in a group, often led by a teacher or coach. It is certainly possible that individuals are able to engage occasionally

in training that would be most relevant to a given individual's improvement during such training in groups. Based on the definition of deliberate practice we argue that the effectiveness of such group training would be inferior to a situation where the individual engages in solitary practice recommended by a coach or teacher (deliberate practice) or engages in solitary practice to attain a particular improvement determined by the individuals themselves (purposeful practice). In the solitary versions of the practice, the individual would be in full control of what to practice and for how long to engage in a particular practice activity.

All effect sizes included in Macnamara et al. (2014) meta-analysis that had met both Criterion 1 and 2 were examined to assess whether or not they provided an estimate of accumulated practice reflected time spent engaging in solitary practice or engaging in practice under individualized supervision of a coach or teacher (Criterion 3, see **Figure 3**). Nearly all effect sizes that were excluded relied on estimates of team practice or practice with groups of other individuals. For example, one of the included effect sizes referred to the study of Duffy et al. (2004) on dart players which included time spent practicing with a partner. Several other effect sizes were excluded because they included the time spent in team practice, such as a study of bowlers (Harris, 2008), of middle distance runners (Young et al., 2008), and of soccer players (Ward et al., 2007). The criterion was applied in a conservative manner so if the study did not request or report a separate estimate for solitary practice it was excluded. The general argument is that different practice activities might have differential effects, and in our review we are trying to assess the relation between the attained reproducibly superior performance and the accumulated duration of deliberate and solitary purposeful practice.

A Reanalysis of the Subset of Studies Included in Macnamara et al. (2014) Meta-Analysis That Meet the Three Criteria for Purposeful and Deliberate Practice

Our reanalysis of Macnamara et al. (2014) meta-analysis considered all of the effect sizes included in their analysis. First we eliminated effect sizes of two studies where the same study participants' data were included twice as independent effect sizes extracted from two different articles as is shown in **Figure 3**. The first duplication involved Ureña (2004) dissertation data and the subsequent publication of the same data in an article under her married name, Hutchinson (Hutchinson et al., 2013). The second duplication concerned the data from Study 2 in Ericsson et al. (1993), which provided half of the data analyzed in Study 1 by Krampe and Ericsson (1996, p. 355). Macnamara et al. (2014, see **Figure 2**) found that the data from Ericsson et al. (1993) was reported as the 2nd highest effect size relating structured practice and performance, when reported for Ericsson et al. (1993). When essentially the same data was reported for Study 1 in Krampe and Ericsson (1996), it was reported as the 155th highest (3rd from bottom) for the experts and 130th highest (28th from bottom) for the novices. In **Supplementary Text S1** (see **Supplementary Data Sheet S1** in the **Supplementary Material**), we describe the reason for this remarkable reduction of the effect size, which is due to a separate analysis of experts' and novices' performance on a task designed for allowing performance by amateurs as opposed to analyzing all participants simultaneously. These three duplicate effect sizes were excluded from further analysis.

We then applied the first, second, and third criteria for inclusion sequentially and report the number of effect sizes that met that criterion in **Figure 3**. In **Supplementary Data File S2** (see **Supplementary Data Sheet S2** in the **Supplementary Material**), we provide a listing of the inclusion or exclusion status for each of the effect sizes considered, and we describe the rationale that led to exclusion of each rejected effect size.

Once the set of effect sizes had been identified as meeting all three criteria, we coded these effect sizes for two dichotomous moderator variables. The first represented objective versus relative measurement of performance, based upon whether performance estimates were derived from objective measurements or membership in groups of differing skill levels. The second moderator variable denoted whether the solitary practice estimates represented deliberate practice, where time was spent engaging in individualized practice activities according to the instruction of a coach or teacher or purposeful practice, and where the individuals were not guided by a coach. More detailed information regarding the procedure for study selection and moderator coding can be found in **Supplementary Text S1**, and a list of the selected studies and their effect sizes can be seen in **Figure 4**. It is worth noting that in their original analyses Macnamara et al. (2014) found significant moderator effects for the domain of performance, but due to the low representation of effects from some of the performance domains we could not replicate this categorical moderator analysis with our present selection of effects (see Fu et al., 2011). Sample-weighted means were calculated using the Comprehensive Meta Analysis software (Version 3.3, Biostat, Englewood, NJ, United States) for effect sizes from the domains of games ($r = 0.50$, $k = 5$), music ($r = 0.71$, $k = 3$), and sports ($r = 0.58$, $k = 5$). It is notable that no effect sizes from the domain of professions met the criteria ($k = 0$) and only the study of Spelling Bee performance (Duckworth et al., 2011) remained for the education category ($r = 0.31$, $k = 1$).

We used the Comprehensive Meta Analysis software to compute the random-effects weighted average of the selected effects. Results indicated a significant positive relationship between accumulated purposeful or deliberate practice and performance ($r = 0.54$, 95% CI = [0.44, 0.63], $p < 0.001$) accounting for approximately 29% of the variance, which is considerably higher than the 14% of explained variance reported in the analysis conducted by Macnamara et al. (2014). The first moderator analysis found that both objective and relative performance were significantly correlated with practice ($r_{objective} = 0.49$, $r_{relative} = 0.65$, ps < 0.001), with no significant difference between the two performance-type correlations [$Q(1) = 1.45$, $p = 0.23$]. This suggested that the positive relationship between practice and performance was not dependent upon whether performance was evaluated through group membership or objective measurement. The second moderator analysis indicated that practice was positively associated with performance whether it was conducted under the guidance of a coach or teacher ($r_{deliberate} = 0.56$, $p < 0.001$) or not ($r_{purposeful} = 0.51$, $p < 0.001$). This difference was not statistically significant [$Q(1) = 0.22$, $p = 0.64$].

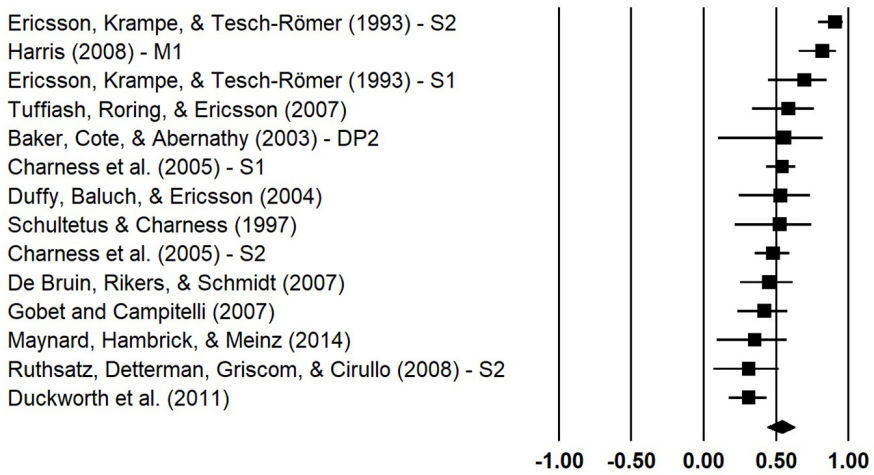

FIGURE 4 | Correlations between purposeful or deliberate practice and performance. Squares represent correlation coefficients for the effects of practice on performance for each listed sample, and lines represent 95% confidence intervals. The marker at the bottom shows the weighted mean correlation. Study naming conventions were kept consistent with those used by Macnamara et al. (2014) for comparison purposes, indicating separate samples (e.g., S1) or measures of practice (e.g., DP2) or performance (e.g., M1).

Finally, we also conducted separate meta-analyses comparing the effects of purposeful or deliberate practice on performance with the effects of structured practice for the subset of eight studies that reported separate estimates for both naïve practice and either purposeful or deliberate practice. Results indicated that purposeful or deliberate practice was more strongly correlated with performance ($r = 0.51$, $p < 0.001$) than was naïve practice ($r = 0.39$, $p < 0.001$), although the dependency of the samples and their practice measures precluded us from formally testing whether this difference could be generalized. Future research with independent training groups will be needed to precisely quantify the differences and test their significance statistically.

Correcting Our New Estimate of Accounted Variance for Attenuation

In this paper we have reviewed the evidence questioning the assumption that a single sum of the accumulated hours of practice is a theoretically valid predictor that would be able to account for the majority of individual differences in attained performance in a domain. Although we don't accept the hypothesized theoretical relation between a single sum of hours of practice and attained performance, we would expect a correlation between more hours of purposeful and deliberate practice aimed at improving some specific aspect of performance and observed increases in the related performance. Both Hambrick et al. (2014) and Macnamara et al. (2014) clearly state that identified correlation between accumulated practice and performance must be corrected for lack of reliability in both the predictor and the performance measure. In an earlier section we reviewed evidence on reliability/validity of the estimates of practice and found that an estimate of 0.6 would be an appropriate measure for estimates of practice over prior years and decades. The reliability of the performance measure was discussed by Hambrick et al. (2014), who found a high level of reliability for chess ratings of international level players. In an interesting analysis, Glickman and Jones (1999) measured the reliability of ratings of chess players and found similar high estimates of Cronbach's alpha equal to 0.95 for highly-rated chess masters but substantially lower Cronbach's alphas equal 0.59 and 0.65 to for players in the average range between 1200 and 1800. Glickman and Jones (1999) hypothesized that the difference was due to the typical players being less involved in tournaments and chess activities. There are surprisingly few estimates of the reliability of performance measures for the samples used in studies of expert performance. Malcata and Hopkins (2014) reviewed research in sports and found intraclass correlation coefficients (ICCs) for athletes' performance within a season and across a year ranging dramatically across domains. For example, cross-country skiing had an ICC for within-season practice of 0.93 and across a year of 0.9, whereas triathlon had ICCs of 0.36 and 0.15, respectively, and canoe slalom had ICCs of 0.31 and 0.27, respectively. Clark et al. (2008) calculated Cronbach's alpha for amateur and professional golfers' 18-hole rounds and found them to be 0.53 and 0.69 respectively. The reliability of performance seems to be higher for the most skilled performers in these diverse domains, but it is clear that it is well below one. Based on the available information we suggest that a reliability of 0.8 would a reasonable estimate. Following Hambrick et al. (2014) recommendation we can now correct the variance estimate of 29% by the lack of perfect reliability in the practice estimates ($r = 0.6$) and for measures of performance ($r = 0.8$). After correction for attenuation, our

estimate for variance accounted for by the accumulated estimates of deliberate and purposeful practice is now 61%. These estimates are consistent with recent studies that show that a larger set of variables describing the practice history of individuals can account for over 50% of variance in chess (Burgoyne et al., 2019) and in SCRABBLE (Moxley et al., 2019).

All of the samples of individuals analyzed in the meta-analyses relating accumulated practice and attained performance only examine data from individuals who exhibit an acceptable level of skill. For example, even amateur players need to have played a lot of chess before they have engaged in a sufficient number of chess tournaments to be given a personalized chess rating. When samples are selected in a manner that is correlated with variables studied – namely, a minimal level of attained skill – then investigators correct for the restriction of range, which estimates substantially larger correlations for the entire population (Schmidt et al., 2008). Macnamara et al. (2016) emphasized (even including the finding in the abstract) that when they limited correlations only to elite performers, who had a substantially higher cut-off for their performance to be included, this estimated correlation, when compared to correlations for samples with a mixture of performers at different levels (amateurs, regional, and international), was much smaller and did not reach significance. Macnamara et al. (2016) do not even mention that this finding is completely consistent with the severe restriction of range. Unfortunately, none of the studies of only elite samples analyzed by Macnamara et al. (2016) passed our three criteria, so future research is necessary to assess if the relation between estimated duration of accumulated purposeful and deliberate practice is significant when only elite performers are included in the analyses.

Beyond Correlations of Sums of Accumulated Duration of Practice and Attained Reproducible Performance

Our review has, so far, primarily attempted to show that imposing criteria for studies before including their correlations in a meta-analysis measuring the relation between accumulated amount of purposeful and/or deliberate practice and attained reproducible performance led to higher correlations than those found for *structured practice* by Macnamara et al. (2014, 2016). As discussed earlier in this paper, nobody has argued that any single hour of practice has an equivalent effect on improving performance. Consequently, we would not expect that completely error-free measures of accumulated practice and performance for the entire population of individuals would be perfectly correlated. Macnamara et al. (2014, p. 1608) reported that their estimates of the correlations between practice and performance were lower than expected, and that "deliberate practice is important, but not as important as has been argued." In contrast, we argue that the current knowledge of the relation between quantity and quality of practice and resulting improvements in performance is steadily increasing as we distinguish the effects on performance from engaging in different types of practice activities, but it is still rather limited. In an earlier section we showed that the duration of effective training is not related to hours of engagement in practice activities for developing the strength and endurance of expert athletes, but the critical aspect of training is the intensity of the practice (Mujika, 2010). Similarly, we reported evidence that some students can engage in solitary practice without improvements in performance (McPherson and Renwick, 2001), and that strategies for improving performance increase in complexity as the attained level of performance is higher (Hallam et al., 2012). There is also an increasing body of research showing that increases in performance as a function of further practice are often not monotonic and exhibit plateaus in the individuals' performance (Gray, 2017), which are not unmodifiable and can be overcome by changes and coach-led practice (deliberate practice). More generally, the development of an individual's performance will be influenced by the quality of acquired basic skills and mental representations. The development of a particular individual's performance requires intermittent assessment of skills, physiological adaptations, and mental representations, along with measurement of objective reproducible performance capturing expertise in the particular domain (Ericsson, 2018a,b,c). Only future research documenting the detailed history of practice and associated improvements of performance and mediating mechanisms will lead to significant advances of our understanding of the potential limiting factors of individual differences in innate ability that constrain the development of superior performance in a domain.

INFERRING GENETIC LIMITS FOR THE EFFECTS OF PRACTICE ON ATTAINED PERFORMANCE

An attempt to measure upper limits of improvability through practice will never be established by correlating a single measure of hours of accumulated practice with attained performance. It is therefore important to pursue an alternative approach which would involve identifying those anatomical and physiological characteristics that *cannot* be changed by practice, diet, or other environmentally controllable factors.

In the original paper, Ericsson et al. (1993) readily acknowledged that there are individual differences in characteristics that are correlated with attained performance yet cannot be modified with any known type of practice. For example, this paper mentioned that research on the development of height and body size (differences concerning the length of bones) indicate that they are determined by genetic factors. This paper even offered some evidence suggesting that there might be inherited factors that influence an individual's ability and willingness to sustain the focus and concentration necessary for successfully engaging in deliberate practice. Even more importantly, this paper reviewed evidence proposing it is possible to dramatically change most anatomical and physiological attributes by engaging in particular types of practice, in contrast to the genetically determined height and body size.

Most of the scientific knowledge about the degree of influence of genetic factors has been based on studies of

twins and the degree to which identical twins are more similar than fraternal twins in a wide range of attributes. The most cited measure of genetic influence is heritability, namely the percentage of variance in individual differences of some measured performance or characteristic that can be accounted for by genetic factors by comparing individuals with differences in the degree of genetic similarity, such as twins and family members. It is, however, important to recognize that "heritability describes 'what is' in a particular sample; it does not connote innateness or immutability," in the words of some of the most influential behavior geneticists (Plomin et al., 2014, p. 47). This implies that we should not assume that heritability estimates for various measures of physical performance of individuals who lead mostly sedentary lives with engagement in mostly recreational physical activities are valid heritability estimates for expert performers, who have engaged in extensive training for years and even decades. In fact, Plomin et al. (2014) agrees and argues that we should consider expert performance as "what could be." The extensive body of research (Ericsson, 2014) shows that expert performance is mediated by acquired cognitive skills and physiological adaptations which differ from those available to beginners. These considerations imply that we should not use heritability estimates derived from novices or amateurs in a domain to reflect the corresponding heritability estimates for individuals who have an extensive training history and perform at a very high level.

There is a large body of twin research that has assessed heritability of scores on tests measuring characteristics believed to be important for success in sports, such as physical fitness, fast-twitch and slow-twitch muscle characteristics, and degree of body fat. These heritability estimates suggest a substantial influence of genes, which has led some researchers (MacArthur and North, 2005) to propose that inherited genes will be the most important factor for predicting elite status of athletes. An early review (MacArthur and North, 2005) suggested that a single gene would explain some 20–40% of individual differences in each of these physical characteristics, such as strength, power and endurance. In the last decade new technological advances have made it possible to describe all the genes in individuals' genomes and do so for many thousand athletes and non-athletes. Genome-Wide Association (GWA) studies have analyzed all this information to search for those particular genes that are associated with a particular superior performance. A recent general review concluded that the genes identified with GWA studies accounted only for a minor fraction of variance predicted by the twin studies (Eynon et al., 2017). So far there appears to be no single gene that accounts for even a few percent of the variance in any of the athletic characteristics (Moran and Pitsiladis, 2017). Even when GWA studies have searched for unique genes in very popular sporting events, such as endurance running, not even a single gene was found to consistently predict significant differences between world-class runners and sedentary adults (Rankinen et al., 2016).

There are many possible explanations for this discrepancy (Georgiades et al., 2017). Most twin studies have collected data on twins who led normal lives and thus had not engaged in intense training necessary to attain elite performance levels. This observation has raised issues about the generalizability of heritability estimates based on the original twin studies (Ericsson, 2014; Georgiades et al., 2017). Another issue is that the similarity of identical twins' physical fitness reflects both their identical genes and the similarity of their engagement in physical activity and potential interactive effects. One interesting approach to distinguish these influences is to search for identical twins where one member of the pair has been engaged in physical activity and the other has been sedentary. Leskinen et al. (2010) identified ten twin pairs meeting those criteria and found reliable differences in the degree of expression of genes in cells of muscles and other tissues consistent with the differences in maximum oxygen consumption and amount of fat. In a recent case study, Bathgate et al. (2018) compared the physical characteristics of a track coach, who participated in many marathons, to his identical twin, who was a truck driver with a sedentary life style. The active twin had dramatically different physiology with a greater maximum oxygen uptake (over 20% higher) and much slower twitch fibers (55% more). The two twins had comparable life styles until age 20, but their lives diverged for the subsequent 30 years. If the track-coach twin had engaged in training typical of elite athletes during childhood and adolescence it is likely that the differences between the two twins would have been even larger. In a large sample of twins, Eriksson et al. (2017) interviewed ten twin pairs reared together, where only one of the identical twins was currently an amateur playing a keyboard instrument and had practiced more than 1000 h more than the other twin, who was not playing an instrument. Eriksson et al. (2017) was unable to identify any systematic environmental factors that could explain the discrepancy. When these twin pairs, except one, had their brains scanned, De Manzano and Ullén (2018, p. 392) found "that even when controlling for genes and early shared environment, there can be observable neuroanatomical differences in both gray matter and white matter microstructure between individuals that differ vastly in musical training." The authors furthermore speculated that the differences between the two identical twins would have been even larger if the music playing twin had been a professional musician rather than an amateur.

Twin research on cognitive ability has also estimated that a substantial portion of the individual differences in performance of tests measuring cognitive ability is heritable (around 50%; Plomin and Spinath, 2002). It has been assumed that superior cognitive ability would be associated with superior performance in domains of expertise across the entire period of development of expert performance. In a review, one of us (Ericsson, 2014) showed, however, that the performance of beginners in a domain of expertise correlates with scores on tests of general cognitive ability, whereas the performance of skilled individuals in the same domain correlates with such test scores at a dramatically reduced level and often cannot be distinguished from chance. In a subsequent review, Ullén et al. (2015) mentioned two studies that would still show significant correlations between performance on tests of general cognitive ability and performance. They

cited a significant correlation between amount of deliberate practice for traditional music performance and performance on a test of working memory and sight-reading performance (Meinz and Hambrick, 2010). Consistent with our earlier described criteria for examining only performance that captures the goal of the music training, we will not discuss this finding further. More importantly, they also cited a significant correlation between intelligence and chess ratings (Grabner et al., 2007). However, in a more recent meta-analysis of the correlation between cognitive-ability tests and chess performance, Burgoyne et al. (2016) found a substantial correlation between test scores of cognitive ability and chess performance for beginners and less-skilled players, but the relations were no longer significant for highly-skilled players. There is an accumulating body of evidence for a gradual disappearance of correlations between performance on cognitive ability tests and domain-specific performance as domain-specific mechanisms are acquired and then mediate the superior expert performance.

Some recent studies have analyzed large samples of identical and fraternal twins to assess the heritability of attained performance in domains of music. Hambrick and Tucker-Drob (2015) examined data on twins among high-school students and found that having engaged in some type of public music event, such as at a minimum receiving a good evaluation at a music competition at the school level, was significantly heritable. When we reanalyzed this data set while defining the music achievement matching the students at the music academy in West Berlin (Ericsson et al., 1993), the estimate of the additive genetic effect was no longer significant (see our **Supplementary Text S1** for details). In another very large sample of over 10,000 twins, Mosing et al. (2014) tested twins on a test of music ability and estimated substantial heritability (40–70%). Mosing et al. (2014) proposed that "results may have differed if a different measure of music ability had been used (e.g., success in the musical world)" (p. 1802). Consistent with the possibility that heritability estimates would not be significantly different from zero when success in the music world was defined as becoming a successful professional musician, the number of musicians that had reached a professional level was reported to be very small (Ericsson, 2016). In response to a request to Mosing and Ullén for an ACE analysis of the effects of genetics on reaching expert-level musical performance (professional status, in this sample) sent shortly after the study was originally published, the authors responded that they were going to publish these results very soon. Now 5 years later, and after many repeated requests for such an analysis there has been no such reporting on the professional musicians in their sample. This group of researchers has published several papers on twins where only one identical twin in a pair is playing music but they limited these analyses to the amateur musicians in their sample (Eriksson et al., 2017; De Manzano and Ullén, 2018).

More generally, Ericsson (2014) reviewed the information of the elite achievement of twin pairs or individual twins of either identical or fraternal type. The review uncovered very few cases, in fact a much smaller number than would be expected by chance based on the proportion of twins in the general population. It is therefore unlikely that studies of identical and fraternal twins will ever provide us with information relevant to estimating the heritability of attaining expert performance.

TOWARD FUTURE INTEGRATED ACCOUNTS OF INDIVIDUAL DIFFERENCES IN ATTAINED EXPERT PERFORMANCE

The expert-performance framework and the proposals by Hambrick et al. (2014), Macnamara et al. (2014) and Ullén et al. (2015) have many agreements. All of them agree that extended practice is necessary to attain expert performance and that genes in the DNA are expressed in response to practice activities, and these genes play a central role mediating the biological changes of body and nervous system. All frameworks also agree that unique genes generate individual differences that are important predictors of successful performance in some domains, such as height in many sports, and that future research in genetics might identify unique genes related to success in various domains of expertise. Our disagreement with Macnamara et al. (2014) and Ullén et al. (2015) concerns their claims of having uncovered limits for how much performance can be improved by practice, in particular that Macnamara et al. (2014) reported limits generalize to purposeful and deliberate practice. Only future empirical research will allow us to describe and measure these limits and then assess whether these potential limits will practically constrain some individuals from attaining expert performance in particular domains.

There are suggestions that future research will be better integrated and combine the two types of traditionally unrelated studies. The first type of traditional research consists of studies analyzing only the GWA of genes to superior performance. The second type focuses on analyzing cognitive mechanisms and detailed analysis of engagement in practice activities and the changes in performance resulting from engagement in these practice activities. Over the last few years geneticists (Georgiades et al., 2017) have expressed the goal of explicating epi-genetic effects on performance, and they propose collecting information about the detailed practice history along with genome-wide mapping of genes so that practice activities involving parts of the body that trigger the expression of genes in corresponding tissues can be identified.

In the future it should be possible to analyze the individual differences in attained absolute performance in a particular domain with regression analysis, where variables include the presence of unique genes, the engagement in particular practice activities, as well as the possible interaction between genetic and practice variables. It is less clear that proposals for including predictors such as measures of personality and general cognitive ability (Ullén et al., 2015), will be particularly helpful in assessing the relative role of the genes, practice and their interactions, as it is currently clear that it is impossible to infer whether these individual differences in general cognitive abilities (Habibi et al., 2018) or personality (Tedesqui and Young, 2017) are the cause or consequence of the extended engagement in practice

and instruction. A major challenge to a regression approach to identifying the predictors of very high levels of performance is that the number of individuals meeting the standards of absolute performance at the highest level is small in each particular domain of expertise. It is therefore unlikely that we can successfully induce knowledge by collecting data from thousands or millions of participants and then use statistical techniques to infer which of the many study variables can predict performance outcomes for new samples using cross-validation methods. This is a well-documented problem for GWA studies that evaluate the potential effects of a very large number of genes (Rankinen et al., 2016) where the probability of spurious associations between genes and performance are high. Earlier in this paper we discussed problems of reducing the variables measuring practice to a single sum of the accumulated hours of engagement in many types of practice activities. In fact, when a larger number of variables measuring different aspects of the practice history is entered into the analysis the amount of explained variance will increase. For example, a recent reanalysis of practice-related variables (Burgoyne et al., 2019) showed that they accounted for over 50% of the variance in chess ratings, even without any corrections for attenuation. In our opinion, we are unlikely to be able to account for all individual differences in attained performance that would be attributable to practice and training. By incrementally including variables measuring at what age certain types of practice activities were initiated and how many hours an individual engaged in certain type of activity, as well as the observable result of that practice, the amount of variance accounted for will slowly increase. This approach might be pursued by some researchers, but it will not address the questions originally motivating our research on expert performance (Ericsson et al., 1993).

The original goal of the *Psychological Review* paper (Ericsson et al., 1993) was to search for and then describe optimal training conditions for improving the reproducible objective performance in domains of expertise. The first two studies examined the daily lives of full-time students in the domain of music, which has had a very long history of developing one-on-one training and thus developed effective practice methods and a common curriculum for students. Within the music academies, students receive training consistent with the definition of deliberate practice, where a teacher assesses the individual trainees, provides guidance for their work during their solitary practice and evaluates their improvement related to the assigned practice goals at weekly lessons. Many domains of expertise can learn something from the training developed in music academies. To make further progress researchers need to go deeper and describe the quality of deliberate practice by examining the cognitive processes mediating effective learning during solitary practice (Coughlan et al., 2014) and/or analyzing detailed behavior during practice from video recordings and performance tests (Miksza, 2015). It is important that researchers objectively describe the structure of the acquired performance by each trainee as well as the processes of their skilled teacher, who assesses that performance and uses this knowledge to guide the trainee's future practice goals. More generally, we would recommend that researchers invite trainees and their teachers or coaches to study the long-term development of absolute performance in the associated domain. In the last few years there are several reports describing the training and performance of World-class athletes in cross-country skiing (Solli et al., 2017), in Nordic combined skiing (Rasdal et al., 2018), and cycling (Pinot and Grappe, 2015). These studies have collected detailed information about each training session, often by downloading data collected during the practice sessions by a device (Pinot and Grappe, 2015) or data entry after each training session (Solli et al., 2017; Rasdal et al., 2018). In all these three cases, dramatic improvements of absolute performance were recorded during the examined time period of 5–10 years, and these changes were closely linked to changes in the duration and/or intensity of particular types of training.

In sum, we believe that a partnership between researchers and individual elite athletes and their coaches would allow relatively unobtrusive documentation of the detailed practice conditions along with the associated changes in performance on the practice task and associated verbal reports of thought processes during learning. This arrangement is very similar to the early research on memory experts, who were brought into the laboratory for extensive testing followed by experiments designed to evaluate hypotheses about the mechanisms mediating the experts' superior performance (Ericsson, 2018a). The primary difference would be that these new studies would focus on expert individuals who are focusing on improving their performance for longer periods. The proposed collaboration should only minimally interfere with the trainees' regular schedule because the researchers would record the data very unobtrusively during practice sessions and then analyze that data as well as invite the athletes to participate in occasional tests of performance in the researchers' laboratories. Based on their analyses, the researchers will propose hypotheses about the cognitive and physiological mechanisms mediating observed improvements of absolute performance, which could subsequently be evaluated by designed experimental sessions with the trainees. The findings from the analyses and experiments will not merely improve our understanding of the conditions of optimal practice. For individual expert performers this arrangement should be beneficial because it would likely provide the financial resources from foundations, granting agencies, and sponsors to the researchers to conduct regular assessments and analyses of changes in performance as well as associated changes in mental representations, physiological adaptations, and perhaps even the associated expression of particular genes in relevant tissues. The accumulation of this type of knowledge will not only benefit teachers and coaches and their trainees in the same domain, but it will also allow scientists to induce general principles for how traits and mechanisms mediating competitive performance can be effectively modified to improve the performance of children, adolescents and adults in a wide range of domains of activities during work and leisure.

AUTHOR CONTRIBUTIONS

KE contributed conception of the review and wrote the draft of the manuscript. KH prepared the data, performed the statistical

analysis, contributed to sections of the manuscript relevant to statistical analysis, and prepared **Supplementary Materials**. All authors contributed to manuscript revision, read and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02396/full#supplementary-material

DATA SHEET S1 | Supplementary Text S1, which provides more details regarding our meta-analytic procedure and reanalysis of the dataset analyzed by Hambrick and Tucker-Drob (2015).

DATA SHEET S2 | Coding for inclusion and exclusion of effect sizes reported by Macnamara et al. (2014).

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Academic (Under)achievement of Intellectually Gifted Students in the Transition Between Primary and Secondary Education: An Individual Learner Perspective

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In the last decade, the Achievement Orientation Model (AOM) of Siegle and McCoach has often been used to quantitatively explore different pathways for academic achievement among intellectually gifted students in educational settings, mostly in secondary education. To study the dynamics of the different components in the AOM, we further examined the inhibiting and facilitating factors associated with academic achievement as experienced by well-performing and underperforming gifted students. Because the transition from elementary to secondary education is a crucial phase for intellectually gifted students, we selected students from the 7th and 8th grade, using purposive sampling. Six gifted students, three well-performing and three underperforming, from two different high schools participated in in-depth interviews. By capturing the lived experiences of six intellectually gifted students in this study, we were able to get more insight into the complex processes that relate to students' (dis)engagement and (under)achievement in school. The findings underline the value of the AOM and stress the importance of taking learner perceptions into account.

Keywords: Achievement Orientation Model, gifted students, underachievement, self-regulation secondary education, qualitative research and analysis, self-regulation

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INTRODUCTION

Since the 19th century, attention has been paid to cognitive talent in the scientific literature (Gagne, 1985; Cravens, 1992). With the rise of research on giftedness, the problem of underperforming gifted students in education was also raised (Dowdall and Colangelo, 1982). Lack of motivation is seen as a possible explanation for underachievement among cognitively gifted students (Whitmore, 1986; Rea, 2000; Cakir, 2014; White et al., 2018). Siegle and McCoach (2005) developed the Achievement Orientation Model (AOM). This model is grounded in previous research on motivation and intellectual giftedness and shows the different factors that determine whether cognitively gifted students (under)achieve. The AOM points at a number of factors related to motivation, task engagement and achievement, namely self-efficacy, goal valuation, environmental perceptions, and self-regulation. Although research on the AOM has revealed the importance of

interactions with teachers (Siegle et al., 2014), and parental involvement (Rubenstein et al., 2012; Brigandi et al., 2018) and the benefits of homogeneous grouping with like-minded peers (Brigandi et al., 2018), some gaps can be pointed out in the existing literature concerning the AOM.

Most research regarding the AOM has used a quantitative approach, and as a consequence little is known about how students perceive the interplay of these factors, or how these factors interact and depend on each other in specific educational contexts. Qualitative research enables delving deeper into students' perceptions of this complex process. There is one retrospective qualitative study on the AOM (Siegle et al., 2014), in which former students looked back on their high school experiences. However, retrospective studies have their pitfalls, as students may not accurately recall past events (Beckett et al., 2001). The study of Brigandi et al. (2018) also uses qualitative research, but this study is limited to one aspect of the AOM, namely environmental perceptions. Gaining more insight into the lived experiences of the students is important to grasp the complexity of the process of motivational development. A limited number of quantitative studies have already pointed out the relevance of studying the AOM during the early school career of cognitively gifted students (Rubenstein et al., 2012; Ritchotte et al., 2014). In addition, other studies have accentuated the transition from elementary to secondary education as a crucial phase for motivational development, particularly for intellectually gifted students (Snyder and Linnenbrink-Garcia, 2013; Coelho and Romao, 2016; Evans et al., 2018). However, qualitative research with a focus on the first grades of secondary education is missing in research concerning the AOM. Furthermore, the AOM has been mainly studied in American school contexts and it remains unclear if the AOM can also be applied to other educational contexts. It would be interesting to also have more context and time specific empirical research on the AOM in a different educational context.

Gaining insight in perceptions of cognitively gifted students in the transition from elementary to secondary education is important for further theory development. We want to take the lived experiences of the subjects on the one hand and the intra individual mechanism they describe on the other hand into account. Meaning that we look at how the process of (under)achievement (conceptualized by the AOM) is actually put together by the students (Byrne and Ragin, 2009). By getting grip on these aspects we are able to gain a deeper understanding of the AOM. This deeper understanding of the students experiences is important to further develop the theory of the AOM. The general aim of this study is to use the AOM as a theoretical lens, to look into in the interplay of factors situated in the model, and to unravel the complexity of the process that leads to (under)achievement and school (dis)engagement of cognitively gifted students after transitioning to secondary education. By using a qualitative research perspective, we aim to increase understanding of the perceived realities of gifted students (Holloway, 1997; Savin-Baden and Howell, 2013), and also to reveal facilitating or hampering factors (from the AOM) for intellectually gifted students' engagement and achievement as described by the respondents themselves.

In what follows, we outline our interpretation of giftedness, situate the AOM within the literature and give further explanation on the need for more qualitative research on motivational development in gifted students and the role of self-efficacy, goal valuation, environmental perceptions, and self-regulation.

GIFTED STUDENTS

Giftedness is a term commonly used in research. However, there is no widely accepted definition of the concept, and assumptions about and criteria for giftedness differ between theoretical models (Gagne, 1985; Sternberg and Zhang, 1995; Renzulli, 1999; Heller et al., 2000; Sternberg, 2003; Siegle and McCoach, 2005; Subotnik et al., 2011). Despite these differences, common features can be found in the models: there are multiple domains of giftedness (e.g., artistic, athletic, cognitive). Also, there is a distinction between outstanding abilities, on the one hand, and fully developed forms of outstanding mastery, on the other hand. Most models are *developmental* in nature, meaning that they assume that outstanding cognitive abilities are gradually transformed into (outstanding) academic performance. In addition, *environmental and personal* factors play an important role in either facilitating or hampering the transformation or development of abilities into academic performance. Depending on the specific model, these factors are conceptualized differently. Across models, then, gifted students are students who excel in a certain domain, taking into account the environmental and personal factors. We therefore address gifted students as 'intellectually gifted' or 'cognitively gifted' in this study.

When talking about 'intellectually gifted students,' underachievement is a frequently mentioned phenomenon within educational contexts (Rubenstein et al., 2012; Snyder and Linnenbrink-Garcia, 2013). Ritchotte et al. (2014) describe underachieving intellectually gifted students as 'a loss of potential for society'. The most general definition of underachievement or underperformance refers to the discrepancy between ability and performance. Gifted underachievement is, just like the concept of giftedness, very difficult to define. Dowdall and Colangelo (1982) found fifteen different definitions of 'underperforming gifted individuals.' The lack of agreement on the concept also contributes to the lack of insight into the problem of underachievement (Schultz, 2002). Reis and McCoach (2000) formulated a definition of underachievement that integrates different aspects of the range of definitions and which is used in this study:

> *Underachievers are students who exhibit a severe discrepancy between expected achievement (as measured by standardized achievement test scores or cognitive or intellectual ability assessments) and actual achievement (as measured by class grades and teacher evaluations). To be classified as an underachiever, the discrepancy between expected and actual achievement must not be the direct result of a diagnosed learning disability and must persist over an extended period of time. Gifted underachievers are underachievers who exhibit superior scores on measures of expected*

achievement (i.e., standardized achievement test scores or cognitive or intellectual ability assessments). (p.157)

Within the group of underperforming intellectually gifted students, we can distinguish between absolute underachievers and relative underachievers (West and Pennell, 2003). In the first category, the student scores below the general level of the class. Within the second category, students do not perform below the class norm but does perform below his or her own abilities. The latter students often stay 'under the radar,' because they still perform relatively 'normally' compared with the rest of their classroom peers (Subotnik et al., 2011). Scholars argue that intellectually gifted students are likely to underachieve when they lack motivation (Rea, 2000; Morisano and Shore, 2010; Cakir, 2014). In the review of White et al. (2018) nine articles on intellectually gifted underachievers were analyzed, and motivation was frequently reported as being lower among cognitively gifted underachievers when compared to cognitively gifted achievers. This difference has been found across a broad variety of self-reported indicators of motivation (e.g., learning goal orientation, achievement ambition and joy for learning). We can therefore conclude that intellectual gifted underachievement is often linked to different types of motivational problems.

ACHIEVEMENT ORIENTATION MODEL

It is clear from previous research that the underachievement of cognitively gifted students is closely related to motivational deficits. Previous research on motivation of under- or well-performing intellectually gifted students suggests that enhancing the engagement and achievement of these students can be a complex process, as many other factors come into play. If we aim to shed further light on the role of inhibiting or facilitating factors that influence the motivational development of intellectually gifted students, the Achievement Orientation Model (AOM) provides a useful theoretical lens.

Previous research on motivation and (under)performing cognitively gifted individuals formed the basis for the AOM (Siegle and McCoach, 2005). Self-efficacy theory (Bandura, 1986), expectancy-value theory (Eccles and Wigfield, 1995) and person-environment fit theory (Lewin, 1963) are underlying theories incorporated into the AOM. In what follows, we will discuss the most important components of the AOM.

The AOM (see **Figure 1**) distinguishes three domains that are important components of the motivation of intellectual gifted students: self-efficacy, goal valuation, and environmental perceptions of support (Siegle and McCoach, 2005). Motivation is a result of the interplay of these three factors, which then enables the students to self-regulate their learning and engage and achieve in school tasks. Through this model we can gain insight into the process and influencing factors that lead to better performance. At the same time we can expect that if these components are not present, the student's motivational development will not be optimal, which can lead to underachievement.

First, the domain of *self-efficacy* entails the students' beliefs that they have the necessary cognitive skills to be successful. Siegle and McCoach (2005) stated that when students have high competence beliefs, they feel efficacious. When intellectually gifted students have doubts about their competence, this can activate maladaptive coping mechanisms (Snyder and Linnenbrink-Garcia, 2013), implying that they use underperformance as a means to avoid situations in which they might fail.

The second domain is *goal valuation*. This refers to the extent to which students consider certain tasks as worthwhile. The aspect of goal valuation is divided into three factors: the intrinsic value (a student's interest in a task), the utility value (the meaningfulness of a task) and the attainment value (the importance students attach to the task as it relates to their conception of their identity and ideals). According to the AOM, students can be motivated by one or more of these factors (Siegle and McCoach, 2005).

The third domain deals with the students' perceptions of support in their learning environment (*environmental perceptions*). The degree of support that intellectually gifted students experience within their environment influences their academic attitudes and achievements. This support or lack thereof can be experienced, for example, through expectations from parents and teachers, the interaction between students, teachers, and parents, and through events at home or at school. It is possible that students who do not experience their environment as supportive have problems with the authority of teachers or school staff (McCoach and Siegle, 2003).

Next to the three domains, *self-regulation* is also an important component in realizing achievement. Self-regulation contains three elements: self-management, personal standards, and self-monitoring (Siegle and McCoach, 2005). Self-management refers to the strategies and skills required to process large amounts of subject matter. These competencies include, among others, time management and study skills. Personal standards entails what the students think warrants 'good enough' performance, and includes setting realistic expectations. Self-monitoring includes, among other things, monitoring of distraction and being able to delay satisfaction (e.g., first carrying out a less enjoyable task and only then completing a satisfying fun task). When the students are motivated and has the skills to self-regulate himself, he can engage and achieve in school tasks.

In addition to self-efficacy, goal-valuation, environmental perceptions and the interaction with self-regulation, teachers, curriculum at school, attitudes of and activities with friends, and the home situation are all assumed to influence this process (Siegle and McCoach, 2005).

It is clear from the AOM that many different factors are assumed to play an influential role in the engagement and achievement of intellectually gifted students. Viewed from this model, when students have a positive attitude toward the three areas: self-efficacy, goal valuation and environmental perceptions of support, and they also have adequate self-regulation skills, this is associated with more task engagement and higher achievement. A less optimal path is likely when students face problems relating to the different domains (self-efficacy, goal valuation, environmental perceptions and self-regulation). According to this model, there is no predefined path for (under)achievement; in many cases it will be a combination of positive and negative

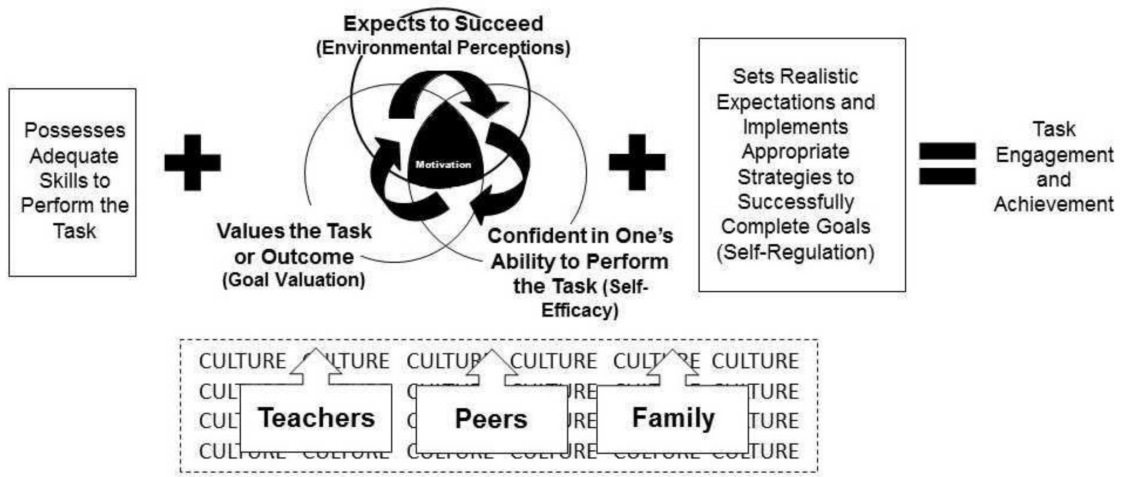

FIGURE 1 | Achievement Orientation Model. Reprinted with permission of Del Siegle.

influences that have a cumulative impact on engagement and achievement (Siegle and McCoach, 2005).

THIS STUDY

The transition from elementary to secondary education is a crucial phase in the school career, particularly for intellectually gifted students (Snyder and Linnenbrink-Garcia, 2013; Vaz et al., 2014; Coelho and Romao, 2016; Evans et al., 2018). When primary education does not offer sufficient challenge or opportunities to develop study skills, this can be problematic in secondary education. For example, we can find a low preference for self-regulated learning (SRL) strategies among intellectually gifted students. These students tend to do well in school for a long time without using learning strategies or self-regulating their learning (Stoeger et al., 2014, 2015) and thus fail to recognize the usefulness of such strategies. When the course content suddenly becomes more challenging in the transition to secondary school, and students cannot rely on SRL skills, they are likely to fail in achieving good grades. Also, if students were not challenged academically in the past, they can adopt an attitude that assumes they will have to make little effort to achieve a satisfactory result (Snyder and Linnenbrink-Garcia, 2013). Because the transition to secondary school is critical for the reasons enumerated above, this study will be conducted in Grade 7 and 8.

In the past, several studies have already been carried out that have demonstrated the usefulness of the AOM for explaining intellectually gifted students' motivational development and the outcomes of this development (Rubenstein et al., 2012; Ritchotte et al., 2014; Siegle et al., 2017; Brigandi et al., 2018). These studies have mainly been quantitative in nature. Because the lived experiences of the students are absent in previous research on the AOM, a qualitative approach was chosen for the current study. As stated in the introduction, there are two qualitative studies on the AOM (Siegle et al., 2014; Brigandi et al., 2018), both which are retrospective or focused on the upper secondary grades. This study adds to this previous research, as students were interviewed about their secondary school experiences while they were in the first years of secondary school, a key transition period that has not been studied so far. By opting for qualitative research and focusing on this particular transition, we can get a richer picture of the experiences of the students and extend previous insights (Holloway, 1997; Savin-Baden and Howell, 2013). There is no assumption of an objective, unambiguous truth in the process of (de)motivation and (under)achievement, but it is assumed that there are multiple realities, formed by individual perceptions (Savin-Baden and Howell, 2013).

In this qualitative study we will focus on the core components of the AOM. No data were gathered on the students' 'home,' 'peers' and 'school' (e.g., the curriculum at school, the professionalization level of the teachers, the attitudes of friends or the social economic status of the family). Accordingly, we will only look at the interplay between the four main components of the AOM (i.e., self-efficacy, goal valuation, environmental perceptions and self-regulation) and how this interplay shapes students' task engagement and achievement in education, as experienced by the students. We opted for purposeful sampling and using a case based approach, because this enables us to provide in-depth descriptions of differently performing intellectually gifted students (Miles et al., 2014;

Corbin and Strauss, 2017). The case-based approach will help us understand the relevance of AOM in specific educational contexts and time (transition primary to secondary).

In this study, we have two research aims:

(1) Identify the components central to the AOM (i.e., self-belief, goal valuation, environmental perception, and self-regulation) in the students' lived experiences.
(2) Explore the factors that can hamper or facilitate student engagement and achievement of intellectually gifted students, and their complex interplay, as experienced by the students.

METHODOLOGY

Sample

To attain informational richness, a purposive sampling strategy was selected, resulting in the selection of 6 intellectually gifted male students from the first and second year of secondary education. Seven secondary schools in the Dutch speaking part of Belgium (Flanders) were contacted, of which only four schools were willing to cooperate. One of these four schools indicated that they did not have students who fit the profile for the study. At another school, the parents did not give permission for their child's participation in the study. The remaining two schools were willing to cooperate: School X and school Y. In School X, there was no specific attention for intellectually gifted students. The school leaders indicated that they were aware of this shortage and therefore they were enthusiastic about participating in this study. At school Y, there was an enrichment pullout program, in which intellectually gifted students learned how to work systematically while stimulating metacognition, motivation and well-being. Intellectually gifted students in school Y were not obliged to participate in this enrichment project.

After informing the schools about our desired respondents (i.e., defining intellectually gifted students), students were selected by the school counselors, using a multi-informed approach. The school counselors and care teams had various conversations with the students, their parents and their teachers. Also they made an analysis of the students' academic performance in elementary education. Based on the academic performances, the various conversations, and taking into account the indicators of students' intellectual giftedness, (e.g., a high capacity for reasoning and problem solving or an excellent memory) they nominated the students. Furthermore, the school counselors were asked to fill out a questionnaire, to substantiate the identification of the children as intellectually gifted (e.g., When it was established that the student was gifted? How was this determined? Do you think this student is currently performing according to his/her capabilities or is he or she underperforming? Why?). Based on the conversations with the teachers and inspection of current academic performances, the school counselor stated that the underperforming students were not absolute but relative underperforming. Of the six selected students, three students were well-performing students and three were underperforming students in school. Only one student had a formal diagnosis of intellectual giftedness (based on an intelligence test). One student had been accelerated by one school year in primary school; another had followed a few courses at a higher grade level in primary education. **Table 1** shows the most important characteristics of the respondents in a more structured way. In order to guarantee the anonymity of the respondents, other names are used.

All of the selected students were attending the first or second year of secondary school in Flanders and were following an academically oriented study track[1] (i.e., classical studies like Latin). Most of the participants were 12 years old. We have no information on their socioeconomic status. Both well-performing and underperforming students were included in this study. After informing the parents, ensuring them of confidentiality and anonymity and obtaining a written consent from both parents and students, six students agreed to be interviewed.

Instrument

To elicit students' personal experiences, a semi-structured interview guide was used with open-ended questions based on the key concepts of the AOM (see **Supplementary Appendix**). The questions were designed in such a way that the different themes of the AOM were discussed. The categories in the interview guide were environmental perceptions, goal valuation, self-beliefs (including self-efficacy) and self-regulation. Some questions were formulated in an open way, e.g., "Do you find it important to perform well at school? Why?" Expected themes that could be addressed with this question are task meaningfulness, self-regulation (personal standards) and environmental perceptions. Others were more focused on one theme: e.g., "When do you think a task is useful?" (goal valuation: utility value). In

[1]Educational tracks in secondary education in Flanders are based on students' academic performance, with the academically oriented track having the highest academic performance standards. Accordingly, during secondary education more and more students change from the academic track to a less academically oriented track (i.e., technical or vocational track), a phenomenon called the "educational waterfall" (Dockx and De Fraine, 2019).

TABLE 1 | Background characteristics of the different respondents.

Respondent	Vince	Sebastian	Thomas	Nick	Jack	Liam
Age	11	12	13	12	12	12
Grade (sec. ed.)	7	7	8	7	7	7
Gifted based on...	Beliefs	Beliefs	IQ-test	Beliefs	Beliefs	Beliefs
School performance	UP	UP	UP	GP	GP	GP

UP refers to a relative underperformance at school. GP refers to a good performance at school.

addition, a specific question was asked about self-monitoring (self-regulation) during the interview. Namely: "Which statement is most relevant to you? And why? (1) I prefer to first do tasks that I like. The tasks that I like less, I postpone as long as possible. (2) I always complete the less fun tasks first; afterward I can complete the tasks that I like to do." The aim of using semi-structured interviews was to give the respondents the opportunity to express their opinions and ideas in their own words so that they could determine the structure of the interview to a large extent (Savin-Baden and Howell, 2013).

Procedure

A pilot interview was first conducted with a non-gifted 12-year-old student. The aim of the pilot study was to determine whether the guideline would work for the age group (is all terminology understandable? Does the pace of the interview allow open conversation, is the interview not too long or do we notice other issues of incomprehensiveness of the questioning?). Afterward, the structure of the guideline was examined and optimized. The interviews were conducted in the spring of 2016 and lasted for 30–45 min. All interviews took place in a quiet room at the students' school. The researcher recorded each interview digitally. The first author conducted the interviews and the analyses. In addition, peer debriefing was used, involving regular discussions between the first author and the other two authors regarding the process, the choices that were made and the conclusions. Peer debriefing contributes to the validity and reliability of the research (Savin-Baden and Howell, 2013).

This study was carried out in accordance with the Social and Societal Ethics Committee of the University of Leuven. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Analysis

First, the interviews were transcribed verbatim. Afterward, the quality was checked by reading the text and listening again to the audio fragments. All misunderstandings were corrected during the second round. The interviews were transcribed in Dutch, only in the last phase of writing this article, the quotes were translated into English. To minimize the loss of meaning inherent in the translation process (Hammersley, 2010), a bilingual researcher made the translation.

To analyze the interview data, thematic analysis was used, using the program Nvivo11. We opted for a mixed coding approach, meaning that both deductive and inductive coding were used (Marshall and Rossman, 1995; Bruce, 2000). In a first phase, deductive coding was used, based on a coding scheme based on the AOM (see **Table 2** for the complete coding scheme). In addition, each code received a positive or negative value (value coding). In a second phase, we added new codes during inductive coding to make sure all the topics addressed by students were coded. First, a within-case analysis was performed: in which each case was examined separately. By using a case-based research approach (in contrast to a variable centered approach), we try to conceptualize the person as an integrated totality, rather than as a summation of variables (Byrne and Ragin, 2009). Afterward, we made a between-case analysis: which themes and obstructing/facilitating factors are discussed across the different interviews regarding the AOM? In order to accomplish the second aim: 'To explore the factors that can hamper or facilitate engagement and achievement of intellectual gifted students, as described by the students.', we compared the codes of well- and underachieving students. To increase the reliability of the coding, we asked a research assistant to code a sample of our data, based on a given coding scheme with the four broad categories and the sub codes. Cohen's κ indicated a fair to good agreement: $\kappa = 0.65$ (Fleiss, 1971). In addition, this step was also discussed via peer debriefing with the second and third author.

RESULTS

First, we use the AOM as a theoretical lens to gain insight into factors inhibiting and facilitating engagement and achievement among intellectually gifted students. Next, we present which factors seem to be likely influential for the engagement and achievement for all intellectually gifted students and we zoom in on the difference between well- and underachieving students. As an example, we illustrate how the interplay between the students' engagement and achievement and these factors was present in the data and perceived by a good achieving versus an underachieving student.

The Achievement Orientation Model

Concerning the first research aim, a first observation was that all components of the AOM were described by the respondents. One component was discussed in a more superficial way, namely self-belief (including self-efficacy), meaning that students answered it in one or two sentences only. The other components were discussed in detail (goal valuation, environmental perceptions and self-regulation), meaning that students talked more extensively about their experiences of these components. When looking at the frequency of the different codes (**Table 2**), this confirms the fact that self-belief was discussed less by the students.

The usefulness of a task, the intrinsic motivation to perform a task or the will to perform well (*goal valuation*) was often discussed related to motivation, task engagement and achievement:

> *Sometimes with those definitions I also think: "What good is it that you know those definitions literally?". It is just good if you understand the definitions and can do the exercises, instead of studying those definitions by heart. Later with your job or with an application they will never ask what the exact definition of a right angle is. I don't think that is useful to know, but I will learn them anyway. (Liam, GP)*

In addition, the respondents indicated if they believed in their own capacities or not, but in a more superficial way (*self-efficacy*): *"I am confident. I experience being smart as something positive." (Jack, GP)* or *"It is not that I say," "Yes,*

TABLE 2 | Coding scheme and number of fragments (N).

Code	*N*	Value coding		
Goal valuation ***Subcodes:*** *- intrinsic value:* *- challenge* *- utility value* *- attainment value*	110	The respondent indicates that he considers learning contents as meaningful and/or interesting.	OR	The respondent indicates that he does not considers a certain task as meaningful and/or interesting.
Self-efficacy ***Subcodes:*** *- fixed mindset* *- labeling*	28	The respondent indicates that he believes he has the necessary cognitive skills to be successful	OR	The respondent indicates that he does not believes he has the necessary cognitive skills to be successful or he indicates that he considers his peers, his family or his teachers as non-supportive.
Environmental perceptions ***Subcodes:*** *- home (parents)* *- teachers* *- peers*	89	The respondent indicates that he thinks that his environment (teachers, peers, parents,. . .) believes in his capacities or he indicates that he considers his environment as supportive.	OR	The respondent indicates that he thinks that his environment (teachers, peers, parents,. . .) do not believes in his capacities or he indicates that he considers his environment as non-supportive.
Self-regulation ***Subcodes:*** *- self-management* *- personal standards* *- self-monitoring* *- transition* *- elementary-secondary education*	82	The respondent indicates that he can set realistic expectations and/or can implement appropriate strategies to successfully complete goals.	OR	The respondent indicates that he cannot set realistic expectations and/or can't implement appropriate strategies to successfully complete goals.

I have talent!". No, it is not that I say, "I am super smart." (Sebastian, UP). Students also talked about the extent to which they thought their environment believed in them and supported them (*environmental perceptions*) and how that influences their motivation, task engagement and achievement.

> *Yes, that's because I had friends then who played computer games all the time. And then I studied much less. . . and then they said: "No, we are not your friends anymore. Just go away. (. . .) I am still bothered by being bullied. There are a few who say that I study a lot and they laugh at me. Because my mom makes me study a lot. (Vince, UP)*

The respondents talked profoundly about their self-regulating skills (including self-management, personal standards, and self-monitoring) and how this influences their motivation, task engagement and performance:

> *I learn my Latin vocabulary. Suppose you have to learn 300 words for your exam by heart. . . then I try to plan it as good as possible so I don't have to do everything at the last minute. That was a bit of a problem at the beginning of the year. I did everything at the last minute and I thought it would work out, but in the end it turned out that things didn't work out so well. So now I try to plan everything as good as possible. (Liam, GP)*

Overall Inhibiting and Facilitating Factors

For the second research aim, it is clear that a multitude of factors (self-efficacy, environmental perceptions, goal valuation, and self-regulation) are related to task engagement and achievement. Although the perceived interplay of factors that lead to (under)achievement is different for each respondent, there are similarities that are present across the six respondents as well as within the distinct groups of well-performing versus underperforming students. Next, we detail the inhibiting and facilitating factors for academic (under)achievement according to the intellectually gifted students in our sample. Afterward we will discuss two cases to show in detail the interplay between the different components.

Self-Regulation

There was a clear difference in the monitoring of delayed satisfaction between well-performing intellectually gifted respondents and the under-performing gifted respondents. All high-performing cognitively students indicate that they would choose to first complete less enjoyable tasks, after which they would engage in the tasks they would like to do: *"It's stupid to finish my homework with tasks that I don't like much. Then you actually end your work with a negative feeling, because you didn't like it. But suppose you finish with a nice task, then you will find that completing those tasks is not a waste of time"* (Liam, GP).

All underperforming respondents opted for the option where they could first complete the fun tasks, only thereafter focusing on the tasks they did not like: *"I'd rather do something fun than do something stupid. So I just try to postpone the stupid tasks." (Sebastian, UP).* Because they want to complete the fun tasks immediately, we can say that these respondents have difficulties with delayed task gratification. Therefore, a lack of self-regulation might be a hampering factor, and being able to postpone a more appealing task appears to be a facilitating factor, for achievement and task-engagement.

> *I've always had a harder time learning. I just can't do it. I sometimes don't know how to write something down. In the lower classes it all*

went smoothly and also at the beginning of the school year, but now the subject matter is more difficult. I didn't study much in the past and now I just have to learn how to study something, and how to study well. (Sebastian, UP)

Sebastian's example confirms the AOM's assumption that a lack of study skills can lead to underachievement when the subject matter becomes more challenging (Siegle and McCoach, 2005). Lacking study skills can therefore be an inhibiting factor to achievement. Interesting in this aspect of self-regulation is the role that the school plays. All six participants indicate that the school tries to teach them SRL strategies. However, when the students' experiences were probed about this offer, all six of the respondents were not interested in the school's program concerning self-regulation strategies: *"Yes 'learning how to learn' does exist in our school; this session is every Tuesday, one day a week. But that's for slightly lesser smart, or average students." (Nick, GP)*

Environmental Perceptions

The between-case analysis shows that a distinction is made between support from parents, teachers, and friends. High-performing respondents point out that they experience their environment, both at home (parents), at school, and with their friends mostly as supportive. This does not necessarily mean that school environments meet their needs. The majority of the respondents spoke about the hampering effect of the lack of challenge and the lack of interesting tasks at school.

I thought it was about Romans and stuff like that, and how it used to be in the past. But it's about the different types of people. Yeah, I like that less. (. . .) If we have to follow the lessons with the whole class all the time, it goes so slooowly. (. . .) I don't think I'm being challenged enough. (Sebastian, UP)

In addition, the respondents spoke multiple times about the transition from elementary to secondary education. This transition was not necessarily a positive experience for the respondents. They indicated that elementary education was more challenging or that secondary education was more challenging in terms of social aspects (different teachers, large school, etc.).

[In secondary school] You also have to deal with every teacher, which is also a challenge in some cases. In primary school you had one teacher. Sometimes you also have to do all the different tasks and remember what each teacher said, that is sometimes. . . yeah. . . (Liam, GP)

Among the underperforming respondents, most of them did experience at least one of their environments as non-supportive. Thomas for example, points out he sometimes clashes with certain teachers. It can be said that Thomas has a negative attitude toward the school and the teachers, which can possibly lead to underperformance.

The teacher gets really mad, then she hits on the table and shouts: "You're not going to make me mad again, are you?" But I don't remain silent. Not that I start to shout, but I do answer. She can't stand that and then she gets even worse. (Thomas, UP)

Goal Valuation

Wanting to attain good grades is the main motive for all respondents to put forth effort in school, regardless of their performance, and this motive is clearly a facilitating factor for achievement at school. Although underperforming students state that this is a facilitating factor in their school achievement, they nonetheless fail to academically engage and achieve:

The grades. If I reach 83 (out of 100), I am not satisfied with that, but it will do the job. I learn for the grades I get. (. . .) I don't always have motivation and I drag my feet. (Thomas, UP); I think school is important to get good grades. (Jack, GP)

In the data we see that the respondents have both positive and negative *intrinsic motivation* experiences, regardless of their performance. Thus, for these respondents, intrinsic value is not a key impeding or facilitating factor in their (under)achievement. Other factors are clearly at stake, as good performing students still achieve when they are not intrinsically motivated, and underperforming students underachieve despite being intrinsically motivated.

Most respondents expressed a lack of intrinsic motivation several times during the interviews. Some found the lessons boring or too slow, others experienced a lack of challenge. Also incorrect expectations of courses sometimes led to a lack of motivation among these students.

An easy task is pretty boring. In the technology-class, it often happens that we get a graded task that we need to complete. We get half an hour for the task and I am done after 10 min. (Vince, UP)

I am not that interested in religion and I find Dutch quite easy. (. . .) Math is my best subject, but this year I think it is all a bit slow. Yes. . . really. I prefer a bit more challenge. (. . .) (Nick, GP)

All respondents made statements that show that they are intrinsically motivated for some courses, as interesting subject matter was pointed out as a main reason for motivation. To a lesser extent, the role of the teacher was also discussed when talking about interesting courses:

In the past, that course actually was a course where I could really easily get high grades without doing much effort, but now I really participate and work in class. And listen to know more about history. I think it's too bad that it is only 1 h a week. (Vince, UP)

Natural sciences, like I said, I really like this. I just find it interesting and the teacher also gives nice lessons by showing experiments and such. (Liam, GP)

Example: The Interplay of Facilitating and Hampering Factors

The within-case analyses reveals that every student shows a unique and complex interplay of facilitating and hampering factors. To illustrate the complexity and uniqueness of the processes that may lead to (dis)engagement and (under)achievement we provide a more in-depth description of two cases, Nick and Thomas, respectively a high achieving and underachieving intellectually gifted student.

Nick (GP) believes in his cognitive skills and knows that he can complete a task successfully (*self-efficacy*). He has high intrinsic motivation, finds most of the subject matter useful and has a drive to perform well (*goal valuation*): *"I just think it's important that you learn, so I just do it."* Nick points out that his parents don't help him anymore with his homework. Still, he experiences his environment as positive: his parents, but also his friends and his school provide support.

> *Since this year my parents no longer help me review the study content. They said after the sixth grade: "Now you have to study independently. Later the study material will become so large that we can't help you review." (. . .) My parents fully support me in my school work. (Nick, GP)*

Yet there is not a complete match between himself and the school (*environmental perceptions*). Although he points out the subject matter is difficult in secondary education, he preferred elementary education because he could work at his own pace. The lessons in secondary education are too slow for him and he prefers to work independently. He likes to research things himself and prefers tasks where he needs to think, something which is not always present in secondary education. Nick knows how to regulate his own learning and how to learn subject matter. His self-regulation skills are developed enough to succeed in difficult tasks.

> *[About a project for intellectually gifted students] It is great, but I really liked it more during elementary school. We really worked together there to discover things, and now it's not really difficult. It's just looking up things and you learn a little bit, but I don't have to think it through. You learn, but you don't think. (Nick, GP)*

We see that almost all factors postulated in the AOM have a facilitating effect on Nick. Nick beliefs in himself (*self-efficacy*), has a lot of intrinsic motivation and finds most tasks meaningful (*goal valuation*) and is able to set realistic expectations and regulate his own learning (*self-regulation*). Only one aspect of a domain, namely *environmental perceptions*, has a minor impeding effect. The interplay of the facilitating effects ensures that Nick is engaged with learning.

Thomas (UP) knows he has a lot of talent, but prefers to keep this to himself. He also indicates that he is not making optimal use of his cognitive skills. He points out that if he worked harder, he could perform better (*self-efficacy*). Thomas has a lack of intrinsic motivation (*goal valuation*). He thinks school is useful, but he cannot make the effort to perform according to his abilities.

> *Yes, school is important. Especially for later, to have a diploma and find a job. Here you just learn about the basics of everything that you will do later. (. . .) On the one hand, it is indeed motivating, but it does not motivate me enough, and I still get good grades even though I am not doing anything for it.*

Next, he experiences both his home environment and his school environment as non-supportive (*environmental perceptions*). Thomas' father recently passed away. According to Thomas, this event has an impact on the motivational process and clearly contributes to his lack of motivation. He does have good friends whom he can count on. He also points out that he does not get the support he needs at school. Thomas refers to the fact that he thinks the teachers are not aware of his high abilities and therefore do not consider this or support him: *"It's not that my grades at school are bad, so the teachers don't worry. A lot of teachers don't even know [that I'm gifted]." (Thomas, UP)*

Thomas has sufficient self-regulation skills to complete a task successfully. However, he sometimes chooses not to use these skills if he doesn't feel like it: *"If we have a test of a language course and I don't like it, then I'll just read instead of write."*

We see that various elements have an impeding effect on Thomas. He beliefs that he can do better (*self-efficacy*) and he states that having the necessary *self-regulation* skills, but he experiences both his home and school environment as non-supportive to his learning (*environmental perceptions*) and is lacking intrinsic motivation (*goal valuation*). The interplay of these different factors contributes to Thomas' cognitive skills not being optimally used, and underperformance occurs.

CONCLUSION AND DISCUSSION

The present study aimed at enhancing our understanding of inhibiting and facilitating factors for academic achievement of intellectually gifted students in the first and second grade of secondary education. The AOM has already proven its strengths in multiple studies (Rubenstein et al., 2012; Ritchotte et al., 2014; Siegle et al., 2014, 2017; Brigandi et al., 2018). By capturing the lived experiences of six intellectually gifted students in this study, we were able to get more insight into the complexity of the process of motivational development that leads to task engagement and (under)achievement as reported by respondents themselves. The insights gained through in-depth self-reported components and relationships provided further evidence of the mechanisms central in the AOM.

The first aim of this study was to identify the components central to the AOM in the students' lived experiences. It is clear from this study that the different core themes positioned within the AOM were found to be present in the data collected from intellectually gifted students through in-depth self-reporting: self-regulation, goal valuation, environmental perception, and self-belief (see codes and sub codes in **Table 2**). The respondents elaborated on all components put forward in the AOM and tackling different subthemes within each theme. Only the aspect of self-efficacy or self-belief was addressed less frequently. We cannot make any clear statement about the underlying reason(s), but we can think about several possibilities. Self-belief, and more specific, self-efficacy is a theme that requires students to reflect upon their own cognitive talents and skills. Maybe the students do not like to brag about their cognitive talents or they may be too insecure to talk about this aspect of themselves. It is also possible that the respondents have never experienced a 'challenging' task or never have thought about 'being smart', therefore students are limited by their own self-insights. This probably also makes it difficult for them to answer. Another possibility is that self-efficacy becomes a more prominent theme only later on

in their educational career, when students experience more school failures.

Second, we explored facilitating and hampering factors experienced by all students. As theoretically expected (Siegle and McCoach, 2005; Ritchotte et al., 2014; Siegle et al., 2017), we found in this study that self-control or self-monitoring (*self-regulation*) is an important factor of students' academic attitude and success. There was a clear difference in the monitoring of delayed satisfaction. 'Fun tasks' were postponed by all high-performing students until less appealing tasks were completed, while all underachievers chose to complete the fun tasks first (direct satisfaction). Earlier research points to the importance of self-control behavior, and the risks of low self-control behavior (Mischel et al., 1989; Krueger et al., 1996; Zimmerman and Schunk, 2011). Researchers have found significant links between self-control and positive social and cognitive outcomes. Self-monitoring or self-control appears to be a good predictor for academic achievement (Pintrich, 2004; Zimmerman and Schunk, 2011; Vermunt and Donche, 2017). Additionally, for self-management skills *(self-regulation)*, the respondents' answers aligned with the theory of the AOM: when a student has not been sufficiently challenged in the past, he cannot fall back on certain study strategies. Data revealed that the participating schools often offer training in self-regulated strategies. However, the respondents indicate that they do not want or need being taught these strategies in this way.

Previous research on the AOM already pointed out that a challenging environment is very important (Brigandi et al., 2018). In this study we also noticed that the way in which the respondents *perceive* their *environments* relates to their academic attitude and performance. Underachievers clearly perceived one or more environments (school, friends, home) as non-supportive. Well-performing students perceived most of their environments as supportive; only 'school' was sometimes mentioned as hampering. Both well- and underperforming students spoke of the hampering effect of the lack of interesting tasks at school. They define interesting tasks as tasks that address higher-order thinking skills and allow students to really learn, which can be linked to higher-level cognitive processes (Bloom et al., 1956). Interestingly, when talking about school, elementary education was mentioned several times. According to the students' experiences, the transition to secondary education does not necessarily imply a more challenging, richer learning environment. Based on the interviews, elementary education is perceived as an environment that provides opportunities for creative, higher-order thinking. Secondary education appears to be more socially challenging (dealing with different teachers, attending a bigger school, making new friends,. . .). Even having an enrichment pullout program at secondary school is no guarantee of intellectual stimulation, according to the respondents in this study; the quality of the program is decisive.

It was striking that "achieving good grades" (*goal valuation*) was mentioned as a crucial motive for studying by the high-performing students. It is an interesting question why this aspect is so present. Is this encouraged in education? Is it because there is an absence of other motives such as intrinsically interesting or challenging tasks? Is it a reflection of students' achievement motivation and performance orientation? Does this in the longer term lead to equally good talent development as other study motives (Pintrich, 2000; Ryan and Deci, 2000; Kyndt et al., 2015)? Further research is needed to answer these questions.

Another observation is that all respondents had both positive and negative intrinsic motivation experiences (*goal valuation*), regardless of their performance. The lack of motivation was, as expected (Whitmore, 1986; Snyder and Linnenbrink-Garcia, 2013), clearly present with the underperforming students. They also spoke, however, about their intrinsic motivation in the classroom. On the other hand, good performing students also frequently reported their lack of intrinsic motivation. Intrinsic value or motivation is acknowledged as an important factor in the development of students (e.g., self-determination theory, Ryan and Deci, 2000). In the case of these respondents, however, intrinsic value was not a determining impeding or facilitating factor in their motivation.

We illustrated how the interplay between the different aspects of the AOM is perceived by well achieving versus underachieving students. As stated in the AOM the well-performing students who show high levels of motivation generally have positive environmental perceptions, goal valuation and self-efficacy. Some components, however, seem to have a stronger influence on the students' motivation than others. This is reflected in the discussed case of Nick; the well performing student, for whom all components were facilitating, only environmental perceptions had a minor impeding effect. A more complex reality is apparent when we look at the case of the underperforming respondent, Thomas. One aspect cannot be disconnected from another, as in this case the interplay of the lack of environmental support, intrinsic motivation and self-efficacy all influenced the motivation, task engagement and achievement of the respondent. By analyzing this case, we can point out the importance of taking into account the AOM in all its complexity, and not isolating one or more aspects.

When interpreting our findings, some limitations need to be taken into account. This study used the AOM as a theoretical lens. On the one hand, it may be too restrictive, because the four factors of the model (self-efficacy, goal valuation, environmental perceptions and self-regulation) were primarily considered, and may have discarded other possible motivational determinants. But on the other hand, the AOM is a broad and dynamic model that maps many different influencing factors. For future research it is interesting to further deepen the core concepts in the model (e.g., self-regulation).

Some methodological limitations are present in this study. First, we used a small purposeful sample. This, however, was a deliberate choice in order to get more in-depth insight from information- rich cases. The case-based approach of this study enabled to take into account the voice of the students, which is not always easy to capture. Longitudinal case study research using observation techniques may provide an even more in-depth picture of these reported realities of students. Second,

five students were involved in the study because of their presumed intellectual giftedness, which had not been formally tested. This belief was grounded in conversations between the school counselor and the student, the parents and the teachers. Thus, multiple sources and actors were consulted before the students were identified as intellectual gifted. Nevertheless, it would interesting to also include a cognitive abilities test in further research in addition to nomination by counselors. Third, the socio-cultural background of the students was not assessed. We assume that students primarily came from middle class backgrounds, but assumption is based only on conversations with the students. It is recommended to assess the students' socio-economic background in further research. Next, all respondents were male. Previous research has shown that there is a bias in the nomination of intellectually gifted students: boys are more likely to be nominated as cognitively gifted than girls (Bianco et al., 2011; Petersen, 2013; Lavrijsen and Verschueren, 2019).

Despite these limitations, this qualitative research is valuable for theory and practice. The components and the processes of the AOM appeared to be applicable in this specific educational context. Allowing students to speak for themselves opened up a source of information that should not be underestimated. Intellectually gifted students from the first and second year of secondary education have no problem to express their experiences, their frustrations and their needs very well. With this article, we want to emphasize the value of taking into account the perceived realities of respondents to obtain rich data both in scientific research and practice.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the guidelines for research ethics of the Declaration of Helsinki and the European General Data Protection Regulation (GDPR) and the Social and Societal Ethics Committee of the University of Leuven with written informed consent from all subjects. The protocol was approved by the Social and Societal Ethics Committee of the University of Leuven.

AUTHOR CONTRIBUTIONS

KB conducted the study. KV and VD contributed to the design of the study, discussed the interview coding, and participated in the writing of the manuscript.

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SUPPLEMENTARY MATERIAL

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CONCEPTUAL ANALYSIS
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Environmental Factors and Personal Characteristics Interact to Yield High Performance in Domains

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Outstanding human performance continues to intrigue experts and the public; however, the focus is often on the individual performer or producer with scant attention given to the additive part played by circumstances and contexts. Using general theories of development (e.g., Bronfenbrenner, 1977, 1986, 2005; Sameroff, 2010) and talent development paradigms (e.g., Ziegler, 2005; Dai, 2010; Subotnik et al., 2011), we examined the interaction of environmental and individual factors on trajectories of high performance within and across varied domains. Public and scholarly awareness of the role played by environments places greater responsibility on education and other societal systems to support talents in varied domains, and to promote evidence of talents' malleability and potential for development.

Keywords: domain specific talent, psychosocial skills, environmental factors, individual differences, high performance

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INTRODUCTION

We begin this article by defining high performance, and the personal and environmental factors that support talent development. Next, we contrast general child development frameworks with those designed to explain talent development. We then provide examples of how personal dimensions work together with environmental contexts to result in outstanding products and performances based on the psychology of high performance in sport, academics, the arts, and professions.

DEFINITIONS OF TERMS

Talent Development

Talent development is a process that propels individuals on trajectories from potential to competence to expertise and, sometimes, to eminence (see Olszewski-Kubilius et al., 2016; Worrell et al., 2018). It is driven by opportunities offered within and outside of school and higher education, including exposure to and practice with domain-specific knowledge and mental and social skills. The foundation of talent trajectories includes general and domain-specific abilities and psychosocial skills that are modifiable by education and training, in addition to appropriately timed opportunities. Thus, participants with potential in a domain

need to engage in talent development in order to transform their potential into domain-specific abilities and accomplishments. Notably, talent trajectories begin at different developmental periods in different domains, whether based on physiological demands or simply tradition. For example, gymnastics training typically starts in the prepubescent years. During adolescence, expectations for performance in gymnastics are far beyond those for a potential diplomat at that age.

There are several reasons why talent development is sometimes not successful. For example, individual interests do not always align with talents and abilities, resulting in less task commitment than required. Individuals may also avoid opportunities to develop abilities due to fear of failure (Clinkenbeard, 2012). Performance domains such as sport and music co-opt such fears and concerns with intense preparation in psychosocial skills. We argue that along with access to the insider knowledge (e.g., career and educational trajectories, grant opportunities, knowledge of the gatekeepers in the field) and resources (e.g., mentors, scholarships) needed for individuals to achieve their goals, psychosocial skills, like domain-specific abilities, are malleable and can be developed as part of any talent development program.

High Performance

High performance refers to meeting benchmarks of exceptional accomplishment for each stage in a talent development trajectory, as determined by domain experts and gatekeepers (Subotnik et al., 2019). That is, individuals in the process of developing their talent at one stage need to demonstrate high performance relative to others to move on to the next (e.g., from competency to expertise). By looking at high performance across a range of domains, we can gain insights into how to better understand and facilitate high performance for individuals at all levels of the talent trajectory.

Environmental Factors

From the moment of conception, individuals are in constant interaction with their environments (e.g., the womb, home, school, society; Bronfenbrenner, 2005). In the context of talent development, environmental factors refer to those that are aimed at propelling the individual along a talent development pathway (Ziegler, 2005). Examples include emotional and financial support from the family, specialized classes, or coaching inside and outside traditional educational contexts, and access to opportunities and experts in the talent domain. Sosniak (1985, p. 417) described this process in the talent development journey of a concert pianist:

> Parents began to consider what other activities they could allow their child to engage in without the possibility of harming his or her music making. Parents began making large sacrifices of time and money to get the child to a better teacher, buy a better piano, and travel to competitions.

If an individual who has tremendous potential in mathematics but less potential in other domains is sent to a school for the performing arts rather than a science magnet school, the environment is less likely to support talent development in mathematics. Although typical sibling rivalry does not provide the context for talent development, competing against a sibling who is highly skilled in the same domain – as described by Syed (2010) on his path to becoming a table tennis champion – provides a cogent example of the home environment supporting talent development.

Personal Factors

Personal factors fall into several categories including general and domain-specific potential and abilities, temperament, personality, psychosocial skills, and mental health. They include wired-in aspects of the individual that are biological in origin. For example, individuals are born with different levels of mathematical cast of mind, musicality, sociability, and tenacity, and these constructs alongside others will interact with each other and the environment and result in differences in accomplishments among individuals. Thus, an individual with superior persistence and high levels of mathematical cast of mind, and an individual with average levels of persistence and superior mathematical cast of mind may both end up as outstandingly creative in mathematics. As Simonton (2005) noted, "most manifestations of giftedness do not depend on the inheritance of just one trait" (p. 271), and "giftedness can develop in contrasting ways for individuals who do not have identical genotypes" (p. 277).

Other personal factors, such as values and beliefs, are learned and acquired as internal standards or principles used to make decisions. These learned characteristics will interact with the inherited ones and can derail or facilitate talent development. For example, all other things being equal, the individual who is more socially adept and appropriately respectful will be more likely to succeed in domains where soliciting finances or patrons to support talent development opportunities are important (Subotnik and Jarvin, 2005; Subotnik et al., 2011). Individual factors can change over time due to influences from within and outside the person, and as noted above, as the person interacts with environmental contexts and chance, producing different talent development outcomes (Subotnik et al., 2011).

GENERAL CHILD DEVELOPMENT FRAMEWORKS

We illustrate the cumulative contributions of environmental and personal dimensions to the flourishing of children and youth with brief descriptions of two prominent developmental frameworks – one by Bronfenbrenner (1977, 1986, 2005) and Bronfenbrenner and Morris (2006), and the other by Sameroff (2010). Following these descriptions, we provide examples of selected talent development frameworks that highlight, to different degrees, a balance between environmental and personal contributions to fulfilling potential.

The Ecological Model of Human Development

In 1977, Bronfenbrenner published a set of propositions based on a series of natural and contrived experiments in which

he articulated how environmental forces affect development. Although much of the discussion in Bronfenbrenner's (1986, 2005) theorizing focuses on the environment, Bronfenbrenner's central argument can be summarized in this way: development is affected by "the progressive accommodation, throughout the life span, between the growing human organism and the changing environments in which it actually lives and grows" (Bronfenbrenner, 1977, p. 513).

Bronfenbrenner's (2005) ecology of human development is illustrated as a series of concentric circles indicating different degrees of environmental influence on the individual, ranging from the intimate to distal forces. The first and innermost circle incorporates microsystems. Microsystems include relationships with parents, siblings, and teachers and have the most direct impact on the developing child. The next circle includes mesosystems, which involve interconnections among the microsystems (e.g., home and school, neighborhood and school). Mesosystems, which Bronfenbrenner (1977, p. 515) defined as "a system of microsystems" contribute to development through the various ways microsystems exert influence on other microsystems. For example, the nutrition and fiscal resources in a home can have a profound influence on a child's ability to learn in the classroom, just as a child's behavior and academic performance in school can lead to changes in the home (Bronfenbrenner, 1986, 2005).

Several environmental dimensions that are less proximal to the individual can also affect development. Exosystems, encompassing the third concentric circle, are the first of these, and refer to societal and environmental contexts that, although not in direct contact with the individual, nonetheless affect individual development through their influences on the individual's microsystems and mesosystems. These can include the media, school board policies, the system of government, legal and educational systems, and transportation systems, all of which can have a marked influence on what happens in the school or home and thus affect the developing individual. Beyond the exosystem is the macrosystem – the fourth of the concentric circles – reflecting societal and cultural ideologies and values that determine the customs and practices used in all of the systems already described (e.g., a society's views on children's rights). Bronfenbrenner reminded us that the way that society interacts with children is crucial to their chances for optimal development, including whether their talents flourish or languish.

Finally, the chronosystem (Bronfenbrenner, 1986) refers to life transitions (e.g., age of school entry or entry into the workforce) and historical events that can affect development. For example, individuals born in the computer and internet age have a different set of experiences than those born in the 1960s; similarly, the terror attacks by fundamentalists over the past two decades and the ongoing war on terror have changed how Muslim youth are socialized and viewed in many countries around the world.

Samaroff's Unified Theory of Development

In a 2010 paper, Samaroff proposed an integrated theory of development incorporating several developmental perspectives. He began with historical trends assigning causation for behavior to nature versus nurture, noting that advances in neuroscience and molecular biology have resulted in nature being preeminent in the first decade of the 2000s, but also pointing out increased recognition over time of the synergy between nature and nurture. After reviewing the concepts of differentiation and integration as non-linear, cyclical forces in developmental and growth models, Sameroff (2010, p. 12) proposed a unified theory based upon an integration of four models "for understanding human growth: a *personal change* one, a *contextual* one, a *regulation* one, and a *representational* one."

Sameroff's (2010) theory building provides insights into how we all develop. First, he integrated biological factors such as health and epigenomics with psychological factors such as mental health and social competence as expressed in home, school, community, and the geopolitical world. Second, he addressed change factors such as puberty or new peer groups, incorporating the influence of both traits and developmental stages as well as Bronfenbrenner's (1977, 1986, 2005) ecological systems, which he called the conceptual model. Third, Sameroff's integrated perspective subsumes the regulation model, which proposes an interaction between self-regulation and other-regulation, with the former being minimal at birth and increasing over the lifespan, and latter being dominant in infancy and becoming less influential over time. In other words, as individuals mature, self-regulation increases in importance relative to the regulation imposed by or inculcated by others. Finally, the unified model incorporates the representational model, which addresses "encodings of experience" (Sameroff, 2010, p. 16) that are internalizations of the external world, and include cognitive, social, and cultural representations reflected in the "interacting identities, attitudes, beliefs, and attributions of the child, the family, the culture, and the organizational structure of social institutions" (Sameroff, 2010, p. 19).

SUMMARY

As Bronfenbrenner (1977, 1986, 2005), Bronfenbrenner and Morris (2006), and Sameroff (2010) made clear, development involves both the individual and the environment. Bronfenbrenner (1977) contended that developmental research needed to go beyond the person and the immediate context and investigate not only the larger formal and informal contexts, but also the interconnections among these contexts. Sameroff (2010, p. 20) also emphasized the importance of these interactions:

> Neither nature nor nurture will provide ultimate truths and neither can be an end in itself. Instead, each can explain the influences of the other because in the end neither can exist without the other. They mutually constitute each other through their unity and interpenetration of opposites.

We now explore how the contributions of both personal and environmental factors are reflected in talent development frameworks designed to explain outstanding performance.

SELECTED TALENT DEVELOPMENT FRAMEWORKS

Several challenges make research and practice in giftedness and talent development especially difficult. The first is that there are no universally recognized definitions of these terms to ensure that study populations consistently represent the concepts under consideration. The goals of talent development are also under debate; for example, which domains are considered valuable enough to warrant public support (Worrell et al., 2019). Nevertheless, several theoretical models have been developed to help organize work conducted in the field, and we provide some examples here. It is noteworthy that all talent development frameworks acknowledge the importance of both the individual and the environment, reflecting basic principles promoted in general developmental frameworks. The talent development models build on these principles to explain the contributions that lead to outstanding performance and creativity in domains of human endeavor.

Paradigms of Gifted Education

Dai (2010), (see also, Dai and Chen, 2013), described the gifted child paradigm as the traditional view of giftedness. In this view, giftedness is operationalized with general intelligence or IQ (nature) and the goal of gifted education is to provide appropriate educational opportunities (nurture) to facilitate development of these intelligent children's potential. Dai and Chen contrasted the gifted child concept with the talent development paradigm (described subsequently), and finally a differentiation paradigm. The differentiation paradigm in gifted education is focused on subjects taught in school. Labeled Advanced Academics (McBee et al., 2012; Peters et al., 2014), this approach addresses differentiation within the school context in the form of curricular and instructional adaptations (Robinson and Robinson, 1982). Rather than using general intelligence as a marker, this paradigm suggests looking at performance in mathematics, or language arts, or other academic content, identifying the students' specific academic level, and adapting the curriculum to meet student needs. Except for its narrower focus on the classroom and school level, advanced academics is compatible with the talent development paradigm, which is exemplified by two models described in more detail below.

Actiotope Model of Giftedness

Actiotope (Ziegler, 2005) is a dynamic model that focuses on interactions between potentially talented people and their environment, animated by adaptation and regulation. As individuals with appropriate abilities and drive work to meet their goals, they adjust in response to successive learning challenges. Those who aspire to excel in a domain acquire both educational and learning capital. Learning capital resources are inherent to the person. They may include physical and health capacities, specific abilities, goals and aspirations, and self-regulation. Educational capital is derived from the environment and capitalized upon by the individual. It includes, for example, systems of instruction, resources of time and money, cultural values and opportunities, and social systems that can enhance or impede progress. Actiotope reminds us that life changes are the constant and that we need to focus our attention on the fluid dynamic between personal and environmental as well as the benchmarks of talent development.

Megamodel

The megamodel (Subotnik et al., 2011, 2018a,b) is premised on principles of talent development derived from a comprehensive review of the psychological science literature in the academic, sport, and arts domains: (1) abilities, especially domain-specific abilities, are malleable and need to be developed to fulfill potential; (2) talent trajectories vary by domain in when they begin, peak, and end; (3) talent development requires the provision of opportunities both inside and outside of school and into careers; (4) these opportunities must be taken up by the talented individual; and (5) over time, taking opportunities and maximizing one's talent are increasingly based on the development and acquisition of psychosocial skills. Principles 1 and 5 are prime examples of the *interaction* of the personal (nature) and environmental (nurture) dimensions. Principle 2, an environmental dimension, incorporates biological factors with the culture of talent development trajectories that have emerged based on tradition. Principle 3, another environmental factor, points toward the different ecological contexts, and Principle 4 describes the responsibility of the individual to engage in talent development, harkening back to Sameroff's (2010) discussion of self-regulation.

HOW ENVIRONMENTAL AND INDIVIDUAL FACTORS WORK TOGETHER CUMULATIVELY TO INFLUENCE TALENT DEVELOPMENT AND HIGH PERFORMANCE

Drawing from Bronfenbrenner (2005) and Bronfenbrenner and Morris (2006), factors external to a talented individual can influence whether the expression of talent is valued and developed or denied. Early experiences with artists, athletes, or scientists result in advanced familiarity with doing well in those domains (Almarode et al., 2017; Olszewski-Kubilius et al., 2017). Schools can either reinforce the value placed by families on sport, academics, or music – or not. Finally, culture (familial, neighborhood, and national) and socioeconomic status profoundly affect how young people choose to or are able to expend their time and efforts (Olszewski-Kubilius et al., in press). Musical instruments and lessons are expensive, as are special sport accoutrements such as golf clubs and golf course memberships. High-quality teachers are often inequitably distributed, with more inexperienced instructors assigned to high poverty schools. Co-curricular opportunities are fewer and farther between in communities without a tax base to support museums, orchestras, ball fields, or innovative industries.

Families with multiple generations of financial stability and accumulated cultural and financial capital are much more likely to support their children's pursuit of a creative career that

requires a longer and more substantial commitment as well as dubious financial payoff for the individual and the family. Thus, children from families that are experiencing instability may be at risk for failing to develop their creative talents. Families that are striving for upward mobility might exert considerable pressure on their children to follow educational paths toward conventional and lucrative careers rather than what are considered "iffy" creative professions in the arts or lower paying jobs in the helping professions. Families that are marginalized in a society as a result of race, ethnicity, family structure, or SES may also eschew traditional educational paths and professions based on the belief that the financial and status rewards typically associated with those paths will not be the same for their children. These families may push their children toward professions such as sport and entertainment that they perceive are more open to and accepting of their group and have a quicker payoff (Olszewski-Kubilius et al., 2017). These are ways in which family status, and specifically parental values, influence opportunities for the recognition and development of children's talents and abilities.

Gender and birth order, particularly, but not exclusively in families that are struggling financially, can influence the distribution of family resources, including money and parental time and attention, thereby influencing opportunities such as higher education or participation in supplemental programs as well as pressure toward particular career choices. First-born children and males may have an advantage in these families. A physical or learning disability can result in parents protecting a child to the extent that talent is unnoticed and underdeveloped or, alternatively, spur parents to focus a great deal of time, attention, and resources toward ensuring the child's opportunities and talent development are not limited nor compromised. Immigrant families as well as parents who did not themselves experience success within school may feel less equipped to advocate for their child in the current educational system. Alternatively, parents who themselves were less successful in school or perceived that they received an inadequate education may be relentless advocates for better opportunities for their children (Olszewski-Kubilius et al., 2018).

Family discord and dysfunction can deter talent development, sapping energy from parents' ability to cultivate a home environment that supports achievement and from children's ability to engage in learning in school. Alternatively, a less than harmonious family environment may produce psychologically independent children who are motivated to prove themselves, have remarkable coping skills, and are extremely resilient in the face of environmental stress and obstacles – all of which will serve them well on the path to talent development. An individual may choose to heal a childhood trauma in a way that maximizes talent (e.g., becoming a doctor after experiencing gang violence) or in a manner that negatively exploits it (e.g., leading a gang). What makes a difference in the paths that individuals take given their experiences and family backgrounds?

One contributing and intervening factor is the influence that parents and other significant others have on their children's beliefs and values, and ultimately their actions and decisions, through the interpretations they provide for significant events that affect the family and child – both within the immediate context and from the broader society. Messages that emphasize positive coping, optimism, hope, resiliency, and self-efficacy can greatly influence students' commitment and persistence to engaging in arduous talent development trajectories within domains. Research indicates that students who are more hopeful report lower levels of perceived stress and higher levels of belonging, self-esteem, educational expectations, perceived life chances, and achievement than their less hopeful peers (Dixson et al., 2017). Supports outside the immediate family, such as caring and attentive teachers, coaches, extended family, and mentors, and outside of school or community programs can compensate for what may be lacking in the immediate family environment and facilitate talent identification and development.

Kiewra (2019) studied adolescents who had excelled in diverse fields such as baton twirling, skating, swimming, equestrian arts, and chess with a particular focus on the contribution of families to their children's accomplishments. He identified a number of ways in which families supported their children, including accessing opportunities in their talent area, finding teachers and coaches, managing their children's schedules so that they can participate in competitions and lessons, and providing both emotional and financial support. In his study, Kiewra reported on the great lengths parents went to to support their children – taking loans to pay for lessons, moving to be near to better coaches and teachers, and even creating opportunities (e.g., chess clubs) where none existed – findings also supported by the early work of Bloom (1985) across diverse talent areas.

The family is just one context in which the developing individual participates, although a primary and extremely influential one. As described by the Actiotope Model (Ziegler, 2005), development occurs *in situ* and results from a complex interaction of person variables and environmental influences. Additionally, the influence is bi-directional, with child characteristics eliciting responses and actions from parents and others and parental actions influencing the development of beliefs, attitudes, values, and personality characteristics of children. Kiewra (2019) noted that although high-achieving adolescents are perceived to have pushy, over-involved parents, in the talented adolescents he studied parental support was led by the intense interest and passion of the child for the talent domain, or what Winner (1996) termed "a rage to master." Children led the way and parents followed with support and resources.

MacNamara et al. (2010a,b) studied the role of psychosocial skills in facilitating pathways toward elite performance in several areas of sport (team and individual) and in music. They asked elite performers to map their trajectory over time and found that rather than a linear path, the participants experienced wave-like patterns of highs and lows across all domains. Although there was considerable individual variation even within fields, classical musicians encountered ups and downs earlier in their trajectories than did rugby, hockey, or track and field athletes. The authors speculated that early success in some fields, such as track and field, may be related more to natural talent, greater physical maturity, and an appropriate physique. In contrast, other fields require considerable investment in the acquisition of technical and tactical skills (e.g., hockey, classical music, gymnastics, ballet, figure skating) before one can perform well.

Thus, personal characteristics may have more influence on initial success in some domains than others, but eventually psychosocial skills become critical in all domains.

Movement to elite levels of performance in all fields requires motivation, deliberate practice or consistent study, and perseverance, but some fields such as music may demand this earlier than others and individuals who possess these skills and personal characteristics will be at an advantage (MacNamara et al., 2010a,b). Some individuals will be deterred by setbacks and perceived failures, such as not being chosen for a team, losing a game or match, sustaining an injury, or losing a competition, and these individuals stop making progress. Alternatively, other individuals will be spurred on by these same experiences to focus on improving their skills, strengthening their commitment, and investing even greater amounts of time and energy. Whether the performer is demotivated or inspired depends on the athlete's or musician's beliefs about their ability, their confidence, and their coping and psychosocial skills. MacNamara et al. (2010b) noted, "The extent to which these micro stages and transitions were experienced as facilitators or debilitators varied considerably and was dependent on how they were interpreted by the individual" (p. 87). Thus, staying on a trajectory toward elite performance is very much dependent upon the interaction between the context (*environmental* aspects of the performance domain) and the characteristics of the *individual* (e.g., age, cognitive maturity, personality).

For all domains of talent, a key transition takes place when individuals take charge of their own talent development and are less reliant on coaches, trainers, and teachers (MacNamara et al., 2010a). This transition involves setting performance and practice goals and engaging in deliberate practice independently. In order to improve their performance, athletes might change coaches and musicians might change teachers. They may also employ extrinsic rewards to help them engage in long, strenuous periods of practice. Several athletes in the MacNamara et al. study noted that they felt they had less aptitude than some others in their sport but had greater drive and willingness to work hard to improve. They witnessed teammates who had enormous talent and potential but who did not transition to elite levels of performance because they did not invest fully in training and practice or come back from failures and defeats. What differentiated the successful musicians and athletes from less successful ones was what the authors termed psychological characteristics of developing excellence, or "PCDEs (MacNamara et al., 2010a)." PCDEs include motivation to succeed, determination, perseverance, pursuit of excellence as a priority, having a vision of what it takes to develop further, goal setting, focus and distraction control, the belief that one can excel, and pressure management.

MacNamara et al. (2010a) suggested that deliberately teaching PCDEs will enable many more individuals with talent to reach higher levels of performance. How elite-level athletes acquire PCDEs is an open and important question for researchers. Many of the elite performers in this study noted that initially they had coaches, parents, and teachers who set practice times and goals for them – that is, these individuals ensured that they engaged in practice and provided emotional support especially in times of struggle and uncertainty (other-regulation). The elite performers gradually assumed the management of their own talent development (self-regulation), perhaps influenced by the modeling or direct teaching of their coaches and instructors and driven by their own desire to improve their performances. Clearly, personal characteristics of the talented individual interact with environmental opportunities and supports to create synergies that help or hinder talent development.

Creative Production

An important goal for the talented individual who seeks to contribute to a field is to generate a creative performance, product, or idea, and make sure colleagues and gatekeepers know about it. No matter the domain, the farther along the trajectory toward eminence, the more likely abilities and acquired techniques, experience, and knowledge are taken for granted. In comparison, psychosocial skills and insider knowledge become increasingly important. Being creative requires courage, self-confidence, concentration, preparing for setbacks, and knowing how the "game" is played. We provide here some examples from the professions and the arts.

Becoming a physician is a long and laborious process. Novices pass through multiple hoops of coursework that require rote memorization and practice. Other than newly informed requirements for reasonable bedside manner and understanding behavior associated with patient compliance, progress is gauged using standardized tests of knowledge acquisition. Success with these early challenges opens doors to a range of specialties, and it is here that excellence is determined by matching the demands of the work and the personal characteristics and values of the individual. Emergency room and trauma surgeons need to remain calm even under the most difficult conditions and provide leadership to teams of medical personnel. Pathologists, anesthesiologists, and radiologists have fewer interactions with patients, yet sometimes are called upon to make decisions or draw conclusions in high-stress situations such as the operating room or courtroom. In medicine and in fields such as software engineering, the most creative outcomes are derived from inspiring colleagues and mentees with a "churn of ideas," including methods for developing new techniques and methods for working productively with healthcare colleagues (McWilliams et al., 2019).

The talent development process of elite classical musicians is, like medicine, relatively traditional, and varies little by country or region of the world. The most significant decision in a career is the match between student and teacher. This match process begins with auditions at a music conservatory where admission is based on whether one of the instructors chooses to take on the candidate. Most of the instruction is conducted one on one. Each teacher conveys the skills and knowledge accumulated from a lineage of her own teachers, sometimes going back decades or even centuries. Students must decide whether or when to break from their teachers' distinct style and forge their own

identity. Young performers must also make judicious decisions with regard to repertoire, managers, and whether to aspire to a solo or orchestral career (Jarvin and Subotnik, 2010).

The culinary arts have changed dramatically from a craft left to servants to one where chefs are celebrated for productions that are both edible and aesthetically pleasing (Aron et al., 2019). During the initial stages of development in the culinary arts, the focus is on the acquisition of techniques for working with various stations in the kitchen, being able to work quickly and respond to changes or problems with alacrity. Over time, a developing chef will work with more "precious" products and conduct more "noble" tasks. To achieve eminence, a chef will need to establish a signature dish or approach and learn to successfully manage the kitchen as well as charm reviewers and clients in the dining room. Again, at higher stages of talent development, personality and psychosocial skills become critical ingredients to success.

SUGGESTIONS FOR FUTURE RESEARCH IN HIGH-PERFORMANCE PSYCHOLOGY

There is a great deal of variation in how well domains are researched (Worrell et al., 2019). Domains with high economic stakes like major league sports, as well as music and business have richer bases of scholarship. Required abilities, benchmarks of success, advantageous psychosocial skills, and insider knowledge are relatively well documented. Within-domain comparisons remain exciting places for discussion and investigation. For example, how do early versus later specializations in sport (gymnastics vs. team sports) differ in terms of abilities, benchmarks, psychosocial skills, and insider knowledge?

Other domains with longer histories of empirical research include drawing and mathematics. Although research in drawing has not had lots of fiscal support, mathematics research has a long history of targeted federal funding as well support from the financial industry. In both of these domains, scholars have been able to identify precursors to future achievement. What is less obvious, however, is what leads to *creative* production beyond deep understanding and commitment.

Domains with robust bodies of research are ripe for policy development, more specifically, policies that can help institutionalize and promulgate talent development in those domains in schools, school systems, or communities. These policies might then serve as models for other domains as they become more evidence based. Many domains of talent are under researched. This may be due to (1) little to no funding associated with study in this area such as creative writing by children, or (2) because the domain is culturally situated such as circus arts or drum corps, or (3) because there are just so many talent domains that a society can support and recognize. Research questions in these domains are wide open, and we hope that young scholars will pursue work on abilities, benchmarks of performance, psychosocial skills, and insider knowledge with gatekeepers and eminent practitioners in each field.

CONCLUSION

Just as general development proceeds *via* the interaction of nature and nurture or the individual and the environment (Bronfenbrenner, 2005; Sameroff, 2010), talent development leading to outstanding performance and sometimes eminence is also dependent on interactions between individuals and the environment (Ziegler, 2005; Subotnik et al., 2018a,b). Although serendipity plays a role, it is also clear that talent development cannot be left to chance alone (Sosniak and Gabelko, 2008; Subotnik et al., 2011). In addition to potential particular to a domain, talent development also requires specific types of environments (e.g., knowledgeable teachers, coaches) and specific types of responses to environmental pressures (e.g., persistence, engaging in deliberate practice). Without an accumulation of all of these interacting factors, talent development is not likely to occur, and potential will remain an unfulfilled promise.

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Self-Regulation and Executive Function Longitudinally Predict Advanced Learning in Preschool

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While the early years are often regarded as a critical period for establishing and supporting the developmental trajectories of delayed and typically developing children, they also represent a critical time for advanced learners. Yet to support advanced learners, a better understanding of sources and mechanisms of precocious early learning is needed. While there is ample research separately indicating importance of executive functions (EFs) and self-regulation for learning more broadly, it remains unclear whether, which, and to what extent EFs and/or self-regulation might account for the incidence of advanced learning in the prior-to-school years. The current study sought to investigate the EFs and self-regulation of 214 3- to 5-year old preschoolers, to better understand the profile of these abilities amongst advanced compared to non-advanced learners. Measures of self-regulation, EF and academic learning were taken at the start of the final pre-school year, and academic learning was assessed again at the end of the year. Results indicated that consistently advanced learning was predicted by socio-demographic factors (age, socioeconomic context), stronger cognitive development (combined EFs, cognitive aspects of self-regulation), yet lower behavioral self-regulation ratings. Results thus identify a profile of cognitive and behavioral characteristics of advanced early learners, which potentiates early identification and helps to clarify the nature and underpinnings of advanced early learning. It also raises questions about whether lower levels of behavioral self-regulation might constrain learning (e.g., difficulty remaining within the structures and sequences of the situation) or is a hallmark that is promotive of learning (e.g., convergent thinking, creativity).

Keywords: advanced learning, giftedness, executive function, self-regulation, school readiness

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INTRODUCTION

It is widely acknowledged that the pre-school years are foundational for establishing and supporting the developmental trajectories of typically developing children, as well as children with developmental delay. It is also a critical time for advanced learners, for whom recognition and appropriate educational experiences can support their precocious development. Advanced early learners – similar to gifted children in the later school years – are often characterized by their strong and rapid knowledge acquisition (e.g., in language, reading, mathematics), good memory, keen interests, high attention to detail, deep levels of investigation and understanding, good problem

solving, and strong self-motivation (Chamberlin et al., 2007; Cukierkorn et al., 2007). Yet the success of these learners is not assured, in the absence of appropriately supportive educational strategies. Where advanced learners are not recognized and supported, ineffectual or misdirected educational experiences place these children at risk of poorer educational, behavioral, social, and emotional outcomes (Gross, 1999; Hodge and Kemp, 2000; Pfeiffer and Stocking, 2000; Cukierkorn et al., 2007; Walsh et al., 2012). Conversely, where educational strategies are tailored to the learner's advanced abilities (e.g., acceleration of advanced learners into kindergarten to accommodate their intellectual needs), their outcomes are similar to or better than their older classmates (e.g., yielding improvements in school adjustment, enthusiasm for learning, self-efficacy; Daurio, 1979; Robinson and Weimer, 1991; Walsh et al., 2012).

While there are some effective early intervention approaches for advanced early learners (Henderson and Ebner, 1997; Walsh et al., 2012), there is need for a better understanding of the sources and mechanisms of advanced early learning. This would aid the identification of viable targets for intervention (e.g., teaching content-specific learning such as early numeracy, and/or supporting the content-free underpinnings of learning) and promote consistency in intervention outcomes. Previous studies of these mechanisms often point to cognitive control processes that facilitate effective and efficient learning. Specifically, evidence of higher levels of executive functions (EFs) amongst advanced learners (Johnson et al., 2003; Bracken and Brown, 2006; Arffa, 2007), as well as the established role of EFs in learning more generally (Bull et al., 2008; Clark et al., 2010; Fuhs et al., 2014), suggest EFs as a possible mechanism for these rapid rates of knowledge acquisition. In this context, better EFs permit: concurrent activation and processing of greater quantities and complexities of information in mind (working memory); resistance to impulses, distractions, and irrelevant information that could detract from learning (inhibition); and the ability to flexibly apply and shift attention with changing demands of the situation and intended learning outcomes (shifting).

It is unclear whether this advantage might stem from superior EF *per se* (a higher capacity in one or more EFs), or from more-effective EF-mobilization strategies (e.g., information processing strategies, problem solving strategies; Ball et al., 1994; Johnson et al., 2003). While effective EF-mobilizing strategies often accompany high EF capacities (Roebers and Feurer, 2016), this is not necessarily so. For instance, previous research suggests cognitively gifted students may be characterized by an advantage in their endogenous EF capacity and/or experiential developmental factors (e.g., learned executive know-how, such as strategies that reduce the executive demands of a task; Johnson et al., 2003; Howard et al., 2013). Accordingly, gifted students' advanced performance may be facilitated, at least in some cases, by more effective learned strategies for deploying EF resources rather than more-rapid development of their endogenous capacities.

There is also some evidence that advanced early learners may have higher levels of self-regulation (Calero et al., 2007), further supporting the possibility that advanced early learning may be better characterized by acquired and more-malleable cognitive control strategies (in contrast to EF capacities, which have proven resistant to broadly transferrable improvements; Diamond and Ling, 2016). To explain the relationship between EF and self-regulation, Hofmann et al. (2012) position EFs as the capacity component of self-regulation, which are dynamically and contextually integrated with goal-setting, motivation, and problem-solving to achieve successful self-regulation. According to this framework, successful learning (as in the case of advanced learners) would be the product of: pursuing a learning objective (goal setting); persisting with this until its conclusion (motivation), even if this becomes difficult (problem solving), as well as the ability to direct sufficient cognitive resources toward learning (capacity, or EFs). In this model, EFs are a necessary but not sufficient condition for successful self-regulation.

However, findings concerning the self-regulation of advanced early learners are mixed, with some findings of increased behavioral problems amongst gifted students. For instance, in one study, similar behavioral profiles were found for gifted children and children diagnosed with ADHD (e.g., similarly high rates of oppositional and hyperactive behaviors; Alloway and Elsworth, 2012). Indeed, there is considerable overlap in the behaviors associated with ADHD and giftedness (Webb and Latimer, 1993). Reasons for this apparent disconnect between advanced cognition and problem behaviors are unclear, with suggestions ranging from: over-excitability being interpreted as hyperactivity; disruptive behaviors that arise from boredom, due to a lack of cognitive challenge (Alloway and Elsworth, 2012); or comparatively lower levels of impulse control amongst gifted students (Johnson et al., 2003).

Understanding whether, which and to what extent EFs and/or self-regulation can account for the incidence of advanced learning in the prior-to-school years is complicated by the fact that EF and self-regulation have tended to be studied in isolation of each other, with little integration in the context of advanced learning. It is also unclear whether advanced learners' profile of performance in these areas should be expected to be uniformly high, or rather might reveal a more nuanced profile of developmental strengths and opportunities. The current study thus sought to investigate preschoolers' EFs and self-regulation together, to better understand the concurrence and profile of these abilities amongst advanced early learners compared to non-advanced early learners. In line with preliminary evidence that advanced early learning might be better characterized by more effective strategies for mobilizing cognitive resources toward learning, it was expected that measures indexing complex integration and application of EFs (e.g., a multi-faceted EF task, cognitive self-regulation index), rather than isolated EFs, would provide comparatively better prediction of advanced early learning when concurrently modeled. Further, in line with findings of more prevalent behavior problems amongst young gifted children (although see Richards et al., 2003 for contradictory findings), it was also expected that advanced early learners would be comparatively lower in behavioral self-regulation. It was anticipated that findings would further clarify the mechanics and mechanisms of advanced learning in the early years, and thereby suggest viable targets and approaches to appropriately support young advanced learners.

MATERIALS AND METHODS

Participants

All children attending one of the 25 participating pre-school centers in metropolitan and regional areas of Australia, identified by their parents as likely attending school the following year, were invited to participate in this study. Centers were selected to be broadly representative of population proportions in terms of their geography (84% metropolitan), socio-economic decile for their catchment area (M = 5.91, SD = 2.24, range = 1–10), and statutory quality assessment rating (i.e., 44% Exceeding, 48% Meeting, 4% Working Toward, 4% unrated against the National Quality Standard).

Parental consent to participate was provided for 217 3-5-year old children, all of whom were identified as likely to be attending school in the subsequent year. While in the Australian context it is most common for children to commence school at age 5, this does not preclude children from commencing younger, as reflected in the smaller number of 3-year-olds (n = 29, with only two younger than 3.5 years) in the sample who were identified as starting school the next year. At baseline, the mean age of the sample was 4.43 years (SD = 0.38, range = 3.20–5.24), with a relative balance of boys and girls (46.5% girls). Children who identified as of Aboriginal or Torres Strait Islander descent comprised 5.2% of the sample, which is in line with population estimates for this age group (Australian Institute of Health and Welfare [AIHW], 2012). Family income was diverse: 10.6% of families qualified for full childcare benefit subsidies (low income); 65.4% of families qualified for some childcare benefit (low-middle to middle-high income); and 24.0% of families did not qualify for any childcare benefit subsidy (high income). Maternal education levels were also diverse: 9.1% did not complete high school; 8.0% completed only high school; 29.9% had completed a diploma, trade, or certificate; 34.8% completed a tertiary degree; and 18.2% a post-graduate qualification. All children spoke English as their first language. This study was approved by the University of Wollongong's Human Research Ethics Committee, and participants were those whose parents provided informed written consent and themselves provided verbal assent to participate.

Measures

Academic Learning

The academic knowledge of participating children was assessed using the *Bracken School Readiness Assessment (BSRA,* 3rd edition; Bracken, 2007). BSRA is a standardized assessment of areas deemed important for school readiness. It includes subscales of colors (10 items), letters (15 items), numbers/counting (18 items), sizes/comparisons (22 items), and shapes (20 items). For each domain, the assessment continues until completion or three consecutive incorrect responses. BSRA has been shown to be predictive of kindergarten teacher ratings of children's school readiness and academic results (Bracken, 2007; Panter and Bracken, 2009). Children's rate of academic learning was examined using multiple BSRA indices, namely: children's raw scores, to evaluate change with age; standard scores, to evaluate change in relative age-adjusted terms; and, finally, established performance thresholds to classify learners as "delayed to average" or "advanced to very advanced". Validity of these classifications is shown through their prediction of clinical diagnoses (e.g., language delay or disorder) and later outcomes (Bracken, 2007).

Executive Functions

Individual EFs were indexed by measures of working memory, inhibition, and cognitive flexibility selected from the iPad-based *Early Years Toolbox (EYT*; Howard and Melhuish, 2017). Specifically, working memory was indexed by the *Mr. Ant* task, which asks children to remember the spatial locations of "stickers" placed on a cartoon ant, and identify these locations after a brief retention interval. Test trials increase in complexity as the task progresses (progressing from one to eight stickers), with three trials at each level, until the earlier of completion or failure on three trials at the same level of difficulty. Working memory was indexed by a point score that estimates working memory capacity, following protocols of Howard and Melhuish (2017). Inhibition was assessed by the *go/no-go* task, which requires participants to respond to "go" trials ("catch fish") and withhold responding on the "no-go" trials ("avoid sharks"). The majority of stimuli are "go" trials (80% fish), thereby generating a pre-potent tendency to respond that children must inhibit on "no-go" trials (20% sharks). After instruction and practice, 75 test stimuli were presented across three 1-min blocks (separated by a short break and reiteration of instructions). Each trial involved presentation of an animated stimulus (i.e., fish or shark) for 1500 ms, each separated by a 1000 ms inter-stimulus interval. In line with protocols of Howard and Melhuish (2017), inhibition was indexed by an impulse control score, which is the product of proportional "go" (to account for the strength of the pre-potent response generated) and "no-go" accuracy (to index a participant's ability to overcome this pre-potent response). Finally, cognitive flexibility was assessed by the *Card Sort* task, which asks children to sort cards (i.e., red rabbits, blue boats) first by one sorting dimension (e.g., color), then switch to the other sorting dimension. The task begins with a demonstration and two practice trials, after which children begin sorting by one dimension for six trials. In the subsequent post-switch phase, children are asked to switch to the other sorting dimension. For all test items, each trial begins by reiterating the relevant sorting rule and then presenting a stimulus for sorting. If the participant correctly sorts at least five of the six pre- and post-switch stimuli, they then proceed to a border phase of the task. In this phase, children are required to sort by color if the card has a black border or sort by shape if the card has no black border. Cognitive flexibility was indexed by the number of correct sorts after the pre-switch phase (Howard and Melhuish, 2017). Each of these tasks has shown good convergent validity with other task-based measures of EF (rs ranging from 0.40 to 0.46) and reliability with children of this age (Howard and Melhuish, 2017).

A measure that requires complex combination of EFs was also administered. *Head-Toes-Knees-Shoulders (HTKS)* asks

children to remember a correspondence between body parts (e.g., head and knees), and then perform the opposite action to what was indicated (e.g., touch their knees when the facilitator says "touch your head"). In doing so it requires children to hold a correspondence in mind (working memory), inhibit the impulse to do as directed (inhibition), and flexibly switch between correspondences across task levels (cognitive flexibility). The task consists of six practice and 10 test trials at each of three levels of difficulty: (1) correspondence between head and toes; (2) correspondence between knees-shoulders and head-toes; and then (3) flexibly switching between the correspondences of head-knees and shoulders-toes. The task continues until completion or failing to achieve at least four points within a level (such that two points are awarded for a correct response and one point for a self-corrected correct response). HTKS has been shown to have good convergent validity with other task- and adult-report measures of self-regulation, predictive validity of academic learning, and psychometric reliability (e.g., α ranging from 0.92 to 0.94; McClelland et al., 2014). Fieldworkers completed the online training module prior to in-field data collection to ensure accuracy of scoring and inter-rater reliability. Performance was indexed by the sum of points awarded across all practice and test trials.

Self-Regulation

Preschool Situational Self-Regulation Toolkit (PRSIST) Assessment (Howard et al., 2019) is an observational measure of early self-regulation that engages children in self-regulatory activities, and rates the child's behavior in each activity in relation to key aspects of cognitive and behavioral self-regulation. The first PRSIST Assessment activity is a group memory card game. In this activity children, in a group of four, take turns trying to find a matching pair of cards (e.g., 8 pairs for 4-year-olds, 14 pairs for 5-year-olds), which takes around 10 min to complete. The second activity is an individual curiosity boxes activity, in which children are presented with a series of three boxes of increasing size and they are asked to guess their contents. The sequence of guessing occurs as follows: first, guess based only on the size of the box (no touching); second, guess after gently lifting the box to feel its weight (no shaking); third, guess after shaking the box (no opening); and lastly, guess after closing your eyes and feeling the object inside (no peeking). This takes around 5 min to complete. Rather that considering the number of pairs found or correct guesses, however, performance is rated by a trained observer in terms of each child's self-regulatory behaviors. Specifically, each child's self-regulation is rated at the end of each activity, with items rated along a 7-point Likert scale representing a judgment of the frequency and/or degree of behaviors relating to cognitive self-regulation (e.g., Did the child sustain attention, and resist distraction, during the instructions and activity?) and behavioral self-regulation (e.g., Did the child control their behaviors and stay within the rules of the activity?). This yielded two sets of self-regulation ratings per child – one per activity – which were averaged for the two activities before aggregating into cognitive (six items) and behavioral self-regulation indices (three items). To ensure inter-rater reliability, each of the four fieldworkers completed the online training module[1]. This was followed by: five joint observations alongside a member of the research team prior to in-field data collection; and inter-rater reliability checks, in which all raters achieved a minimum correlation between ratings greater than $r = 0.70$, a mean difference in ratings less than 0.75 points and at least 80% of item ratings within 1 point. This measure has shown good construct validity, reliability (α ranging from 0.86 to 0.95), and concurrent validity with task-based self-regulation (*r*s ranging from 0.50 to 0.63) and school readiness measures (*r*s between 0.66 and 0.75) (Howard et al., 2019).

Demographics

Demographic covariates

Parents reported on demographic information used as covariates for analyses. These were: child's age (the date of assessment minus date of birth); child's sex (1 = male, 2 = female); the Australian Bureau of Statistics [ABS] (2012) Socio-Economic Indexes for Areas (SEIFA), which is a postcode-level index of socioeconomic decile created by the ABS by combining census data on factors such as education, household income, and unemployment. This area-level index was used over the family income variable given its increased sensitivity (reported in deciles) over the three wide income bands utilized to capture eligibility for childcare benefit.

Procedure

All tasks were administered to children in a quiet area of their pre-school center in five sessions across the same day, to maximize children's attention and minimize fatigue. Measures were administered in the same order to all children, as follows: (1) BSRA; (2) PRSIST curiosity boxes and HTKS; (3) Mr Ant and Go/No-Go; (4) PRSIST memory; and (5) Card Sort. Each session took 10–20 min to complete, and were done near the start of children's final pre-school year (March–April 2018). PRSIST raters were not involved in BSRA administration and were blind to EF and BSRA scores at the time of rating. BSRA was again conducted near the end of the year (October–November 2018), also in a quiet area of the child's pre-school center.

Analytic Approach

Multinomial logistic regression was used to examine the associations of children's start-of-year cognitive and demographic data with end-of-year learner classifications. To do this, all participants were categorized using BSRA standard (age-adjusted) scores and classifications as: (1) "not advanced," on the basis of being at or below age expectations at both time points; (2) "no longer advanced," on the basis of children's scores being "advanced" or "very advanced" at the start of year, but at or below age expectations at the end of the year; (3) "newly advanced," on the basis of being at or below age expectations at the start of the year and advanced at the end of the year; or (4) "consistently advanced", on the basis of showing advanced performance at both time points. The referent group for all multinomial regression analyses was the "not advanced" group, to investigate characteristics that differentiated advanced learners from those consistently at or below age expectations.

[1] http://www.eytoolbox.com.au

RESULTS

Initial Data Exploration

Initial data exploration indicated that one child (0.5%) did not complete the Card Sort task due to early departure on the day of assessment and 27 parents (12.4%) declined to provide their postcode for purposes of SES estimation. In these cases, the modal SEIFA decile for the preschool catchment area was used (which, in the majority of cases, corresponded to the sole SEIFA decile for children attending that service). This resulted in loss of only one data point. Subsequent data exploration indicated that the assumptions for multinomial logistic regression were met for the analytic sample. Specifically, in a linear regression predicting BSRA standard scores, despite a strong correlation between PRSIST subscales (and modest associations for other predictors; **Table 1**), all potential predictors showed VIFs well below 10 (range = 1.04–2.61), thereby justifying their concurrent inclusion in multinomial logistic regression analysis.

Prevalence of Learner Groups

As expected, prevalence rates for each learning group were consistent with theoretical estimates (i.e., 10–15%) of the prevalence of advanced/gifted learners (Gagne, 2003). That is, at baseline there were 35 (16.1%) children identified as advanced or very advanced in academic knowledge by their BSRA scores. At end-of-year follow-up, there were 28 children (12.9%) whose performance identified them as advanced or very advanced. Yet children did not always remain in their initial category: 172 children (79.3%) were not advanced at either time point; 17 children (7.8%) were advanced at baseline, but no longer at follow-up; 10 children (4.6%) were not advanced at baseline, but were at follow-up; and 18 children (8.3%) were consistently advanced at both time points. An evaluation of raw BSRA scores suggested that this reflected a difference in the *rates* of knowledge acquisition, as raw scores improved or remained stable across all four groups (see **Table 2**). As such, this pattern demonstrated differing trajectories of learning amongst the sample; while some children started and remained high (or average-to-low) in academic knowledge, other students showed a slower rate of learning (i.e., started high, but a slow-to-nil rate of change over the year meant they were no longer advanced for their age by year end) or a faster rate of learning (i.e., started average-to-low but showed a rapid rate of knowledge acquisition that led to them being advanced for their age by end of year). While the "not advanced" group included a small number of children who were very delayed (n = 5) or delayed (n = 29) at baseline, a number of these children (n = 16) improved to average by the end of the year. As such, to best capture the full range of school readiness in pre-school settings, these children were retained for analyses. Patterns of results did not differ with their exclusion.

Predictors of Early Advanced Learning

The presence of these differing learning trajectories justified subsequent analyses, which examined self-regulatory, EF, and demographic predictors of each advanced learning group, relative to children who were not advanced at either time point. Descriptive statistics of these predictors are provided in **Table 3**. Results of the multinomial logistic regression (see **Table 4**) indicated that few variables significantly predicted differences for the "no longer advanced" or "newly advanced" group compared to the "not advanced" group. Children within the "no longer advanced" group were more likely to be male than female compared to the not advanced group (*RRR* = 0.23, 95% CI = 0.07 to 0.80, p = 0.021). Children in the newly advanced group were more likely to reside in higher-SES areas than the not advanced group (*RRR* = 1.60, 95% CI = 1.11 to 2.32, p = 0.013). No other predictors achieved significance, although this should be considered in relation to the relatively small cell sizes for these groups (i.e., 17 and 10 children).

In contrast, a broad range of factors significantly differentiated the consistently advanced learner group from the not advanced group (**Table 4**). Specifically, the consistently advanced group was characterized as: having higher scores on HTKS (*RRR* = 1.03, 95% CI = 1.00 to 1.06, p = 0.035), but not on individual EF tasks (working memory: p = 0.436; inhibition: p = 0.910; cognitive flexibility: p = 0.113); cognitive self-regulation (*RRR* = 3.62, 95% CI = 1.49 to 8.80, p = 0.005) and behavioral self-regulation (*RRR* = 0.28, 95% CI = 0.12 to 0.66, p = 0.004); being younger (*RRR* = 0.02, 95% CI = 0.00 to 0.17, p < 0.001); and living

TABLE 1 | Correlations amongst continuous predictors and Bracken School Readiness Assessment (BSRA) standard score.

		1	2	3	4	5	6	7	8	9
1	Age (T1)	–	−0.20*	−0.05	0.29*	0.33*	0.30*	0.29*	0.15*	0.28*
2	BSRA		–	0.17*	0.35*	0.26*	0.10	0.25*	0.19*	0.33*
3	SEIFA			–	0.01	0.22	−0.13	0.02	−0.06	−0.06
4	HTKS				–	0.39*	0.35*	0.36*	0.34*	0.38*
5	PRSIST_C					–	0.75*	0.48*	0.34*	0.39*
6	PRSIST_B						–	0.43*	0.36*	0.24*
7	Mr Ant							–	0.30*	0.37*
8	Go/No-Go								–	0.19*
9	Card Sort									–

*Age at baseline is analyzed here, given this is the age at which these assessments were taken. BSRA represents standard (age-adjusted) scores used for subsequent classification and analyses. *p < 0.05.*

TABLE 2 | BSRA raw and standard scores by learner group.

Learner group	T1 Raw score M (SD)	T2 Raw score M (SD)	T1 Std. score M (SD)	T2 Std. score M (SD)
Not advanced	43.79 (13.95)	55.19 (13.55)	94.47 (11.30)	95.17 (11.42)
No longer	66.35 (6.41)	67.94 (6.36)	117.35 (2.45)	107.69 (4.30)
Newly	52.20 (14.76)	72.70 (5.91)	104.30 (7.23)	117.80 (2.94)
Consistently	67.06 (6.98)	75.39 (4.38)	121.56 (5.26)	122.83 (5.32)

Not advanced is the reference category, referring to the majority of children who were at or below age expectations on BSRA at both time points. No longer refers to children who were advanced for their age on BSRA at baseline, but not at follow-up. Newly refers to children who were not advanced for their age at baseline, but were at follow-up. Consistently refers to children who were advanced on BSRA for their age at both baseline and follow-up. T1, baseline (start of year). T2, follow-up (end of year). Std. Score, Bracken School Readiness Assessment's age-adjusted school readiness score.

TABLE 3 | Descriptive statistics for baseline predictors by learner group.

	Not advanced M (SD)	No longer M (SD)	Newly M (SD)	Consistently M (SD)
Demographics				
Age (Time 2)	5.01 (0.37)	5.01 (0.38)	4.92 (0.44)	4.77 (0.44)
SEIFA decile	5.80 (2.18)	6.47 (1.84)	7.50 (2.01)	7.22 (1.80)
Executive function				
HTKS	20.69 (22.28)	31.06 (30.42)	32.80 (31.88)	32.72 (26.37)
Mr Ant (WM)	1.49 (0.94)	1.86 (0.79)	1.67 (1.28)	1.70 (0.94)
Go/No-Go (Inh)	0.56 (0.19)	0.66 (0.21)	0.63 (0.19)	0.58 (0.12)
Card Sort (CF)	4.34 (4.08)	6.53 (4.42)	4.40 (4.22)	6.22 (3.67)
Self-Regulation				
PRSIST (CSR)	3.21 (1.21)	3.64 (1.33)	3.33 (1.52)	3.47 (0.97)
PRSIST (BSR)	4.33 (1.21)	4.49 (1.00)	4.15 (1.54)	3.89 (1.17)

Not advanced is the reference category, referring to the majority of children who were at or below age expectations on BSRA at both time points. No Longer refers to children who were advanced for their age on BSRA at baseline, but not at follow-up. Newly refers to children who were not advanced for their age at baseline, but were at follow-up. Consistently refers to children who were advanced on BSRA for their age at both baseline and follow-up. SEIFA, Australian Bureau of Statistics' area-level Socioeconomic Indices for Areas, derived from postcode-level socioeconomic census data. HTKS, head-toes-knees-shoulders task; WM, working memory; Inh, inhibition; CF, cognitive flexibility; PRSIST, preschool situational self-regulation toolkit assessment; CSR, cognitive self-regulation; BSR, behavioral self-regulation.

TABLE 4 | Association of predictors with children's learner group membership.

	No longer vs. Not advanced			Newly vs. Not advanced			Consistently vs. Not advanced		
	Exp(B)	95% CI	*p*	Exp(B)	95% CI	*p*	Exp(B)	95% CI	*p*
Age (Time 2)	0.19	0.03–1.15	0.071	0.16	0.02–1.41	0.099	**0.02**	0.00–0.17	<0.001
Sex	**0.23**	0.07–0.80	0.021	0.32	0.07–1.46	0.141	0.56	0.17–1.86	0.340
SEIFA	1.27	0.97–1.67	0.084	**1.60**	1.11–2.32	0.013	**1.53**	1.13–2.08	0.006
HTKS	1.01	0.99–1.03	0.379	1.03	0.99–1.06	0.104	**1.03**	1.00–1.06	0.035
Mr Ant	1.01	0.49–2.09	0.981	0.95	0.37–2.45	0.916	1.39	0.61–3.20	0.436
Go/No-Go	16.47	0.57–478.35	0.103	6.40	0.09–436.14	0.389	1.24	0.03–47.66	0.910
Card Sort	1.15	0.99–1.34	0.068	1.00	0.82–1.21	0.999	1.15	0.97–1.36	0.113
PRSIST (CSR)	1.45	0.71–2.97	0.309	1.73	0.65–4.64	0.273	**3.62**	1.49–8.80	0.005
PRSIST (BSR)	0.79	0.38–1.64	0.522	0.58	0.22–1.55	0.280	**0.28**	0.12–0.66	0.004

Exp(B) indicates the relative risk ratio, which can be broadly interpreted as the proportional increase in relative risk/chance of the outcome (being in a given advanced learner group) with a one-unit change in the predictor variable. Significant relative risk ratios are identified in bold. Not advanced is the reference category, referring to the majority of children who were at or below age expectations on BSRA at both time points. No Longer refers to children who were advanced for their age on BSRA at baseline, but not at follow-up. Newly refers to children who were not advanced for their age at baseline, but were at follow-up. Consistently refers to children who were advanced on BSRA for their age at both baseline and follow-up. SEIFA, Australian Bureau of Statistics' area-level Socioeconomic Indices for Areas, derived from postcode-level socioeconomic census data. HTKS, head-toes-knees-shoulders task; PRSIST, preschool situational self-regulation toolkit assessment; CSR, cognitive self-regulation; BSR, behavioral self-regulation.

in higher-SES areas (*RRR* = 1.53, 95% CI = 1.13 to 2.08, $p = 0.006$). Child sex was not a significant predictor of being in the consistently advanced group compared to the not advanced group ($p = 0.340$). Given that all variables were included in the regression simultaneously, this indicates unique and independent prediction of each of these factors even after controlling for all other included variables. As a final step, analyses were replicated for all children who were advanced at follow-up (i.e., consistently and newly advanced children) referenced to the not advanced group. The pattern of results was maintained, such that significant predictors of being in the advanced group were: age, *RRR* = 0.05, 95% CI = 0.01 to 0.24, $p < 0.001$;

SEIFA, *RRR* = 1.55, 95% CI = 1.21 to 1.99, $p = 0.001$; HTKS, *RRR* = 1.03, 95% CI = 1.01 to 1.05, $p = 0.013$; cognitive self-regulation, *RRR* = 2.70, 95% CI = 1.35 to 5.42, $p = 0.005$; and behavioral self-regulation, *RRR* = 0.38, 95% CI = 0.19 to 0.76, $p = 0.006$.

DISCUSSION

The current study sought to investigate the cognitive and behavioral profile of advanced academic learners in the pre-school years. Results from the longitudinal analysis of start- and end-of-year data identified that advanced learning was predicted by socio-demographic factors (i.e., age, socioeconomic context), cognitive factors (i.e., combined EFs, cognitive aspects of self-regulation) and behavioral factors (i.e., behavioral facets of self-regulation). While for most predictors advanced learners showed an advantage in these abilities, they also showed significantly lower levels of behavioral aspects of self-regulation. These results identify a profile of cognitive and behavioral characteristics of early advanced learners, which potentiates early identification and helps to clarify the nature and possible underpinnings of early advanced learning.

The socio-demographic factors that were associated with end-of-year advanced learning were the child's age and socioeconomic context. Age was negatively associated with advanced learning, such that younger children were significantly more likely to have advanced academic knowledge (of letters, colors, shapes, numbers, sizes). While this may seem counterintuitive, this finding must be considered in the context of the age-relative nature of this classification and narrow age range of the current sample. That is, school readiness standard scores identify children's academic learning progress relative to their age, such that a young child who has an identical score to an older child will be characterized as comparatively more advanced in their academic knowledge, for their age. Further, all children in the current sample were identified by their parents as likely to be attending school the following year. Younger children are more likely to be accelerated into school if they are advanced in their learning relative to age peers, whereas comparatively older children with lower levels of readiness for transition are more likely to be kept in preschool for another year. This was in line with the current result, wherein younger children in their final pre-school year were more advanced in their learning than older children after age standardization of BSRA scores.

That a child's socioeconomic context also predicted advanced levels of learning was in line with previous findings of a socio-economic gradient for academic achievement (Considine and Zappala, 2002). Specifically, Considine and Zappala (2002) found that school performance was predicted by a range of social factors (e.g., unexplained school absences, child gender) and economic factors (e.g., parental education, housing). Indeed, a meta-analysis of more than 100,000 students indicated a moderate to strong SES effect on academic achievement (Sirin, 2005). It is thus unsurprising that age and SES were strong predictors of whether or not a child was an advanced learner in the current study, over and above the variability accounted for by cognitive and behavioral indices. The lack of national curriculum in Australia, which is instead governed by an *Early Years Learning Framework*, suggests this is not merely a proxy for high-quality preschool provision or curricula. Indeed, there was little clustering of advanced learners within centers. Among the 25 participating centers, one center had four persistently advanced learners (of nine participating children at that center), one center had three advanced learners (out of nine children), two centers had two advanced learners (out of 15 children), and seven centers had one advanced learner (out of 60 children).

There is also ample research suggesting an advantage in EFs – and especially working memory – amongst gifted learners (Johnson et al., 2003; Arffa, 2007; Howard et al., 2013). A study by Visu-Petra et al. (2011) highlighted the role of EFs across the spectrum of learners, such that individual differences in EF accounted for 50% of the variability in students' academic performance (see also van den Bos et al., 2013; Shaul and Schwartz, 2014). However, the current results suggest that it may not be individual and isolated EF capacities *per se*, but rather their effective combination, mobilization and application in real-world contexts (e.g., paying and sustaining attention during learning experiences, cognitive engagement in learning tasks, ability to be self-directed) that are better predictors of advanced learning. While there is general consensus that EFs are involved in cognitive and behavioral self-regulation – such as using working memory resources to maintain goals in mind, inhibiting distractions, and flexibly deploying attention in service of one's goals (as was the case for the HTKS task) – the two are not synonymous. In an educational context, for instance, failure to acquire new learning can result from never deciding to invest energy toward learning (goal setting), giving up early (motivation), having insufficient strategies to overcome barriers to learning (problem-solving strategies), or insufficient cognitive resources to concentrate on and work with targets of learning (capacity). Only the latter pertains to EFs, although self-regulatory failure can arise from a failure in any of these aspects. This does not contradict or diminish the role of EFs in learning, or as a characteristic advantage amongst advanced learners. Rather, it suggests that the EF advantage of advanced learners may more accurately be characterized as more effective combination, application, and integration of EFs within complex cognitive undertakings, in the presence of sufficient (high) EF capacity for the task at hand.

While the cognitive dimension of self-regulation was higher amongst advanced learners in the current study, these children were also characterized by lower levels of behavioral self-regulation. However, this finding should be interpreted in light of the dimensions of behavioral self-regulation that were assessed, namely: controlling behaviors to remain within the rules and requirements of the activity; remaining seated, and not overly fidgeting; and following social expectations of the activity (e.g., taking turns, not talking over others, acknowledging others' successes). There are multiple plausible explanations for this discrepant profile of abilities. For instance, for advanced learners with high cognitive self-regulation, requirements such as waiting for others who may require additional time (or, rather, may be

more impulsive and may be rushing the advanced learner while they consider their options) may be especially difficult. Lower levels of behavioral self-regulation thus may be a consequence of advanced learning, as noted in prior studies that indicate slow pace and repetition as sources of boredom, frustration and underachievement for gifted children (Baker, 1996; Gallagher et al., 1997). It may additionally be that behaviors associated with high achievement are misconstrued as behavioral dysregulation, such as in cases where "off-topic" questions from gifted students are dismissed by educators (Vialle and Rogers, 2009), even though the question is perfectly on topic but takes a creative interpretation or is a number of steps ahead (as illustrated by the following question from a preschooler: "If a dog had six legs, would it run faster?"; Vialle and Rogers, 2009, p. 33). As the current study is not able to determine between these options, this remains a worthwhile area for further investigation.

While the robustness of the current results is supported by the relatively large and diverse sample, longitudinal data, and multiple measures, there are nevertheless limitations that qualify these findings. For instance, low cell sizes (e.g., for no longer advanced learners) precluded a comprehensive evaluation of the characteristics associated with changes in learning trajectory. Further investigations in this area could identify targets for intervention or prevention to ensure all students are achieving to their potential. At present, the reasons for these changes in group membership are unclear (e.g., regression to the mean, environmental precursors; Gross, 1999). Further, the current analysis presumes four categories of learner, but more are plausible (e.g., very delayed, delayed, average, advanced, very advanced). Larger and more longitudinal data sets would be required to investigate the merits of these classifications, and how characteristics might change across them. Lastly, given the focus of the current study was on integrating EF and self-regulation data, a non-exhaustive range of additional factors were considered. There are other plausible environmental factors (e.g., child's attendance at high-quality preschool, home learning environment) that could be expected to exert similar or greater influence.

Notwithstanding these limitations, the current study suggests an interesting profile for consistently advanced early learners, in terms of cognitive strengths (i.e., coordination and application of EFs to complex cognitive tasks) and aspects of behavioral regulation that were seemingly not as strong. This is in contrast to previous findings that imply that EF capacities appear greater amongst advanced learners–capacities that are notoriously difficult to shift in a way that achieves flow-on benefits to real-world outcomes. Instead, the current results suggest that it may instead (or in addition) be that more malleable aspects of performance are contributing to incidence of advanced learning, suggesting the possibility that these strategies might be fostered for the benefit of more learners. In demonstrating a non-uniform profile of development for advanced learners, these results also raise questions that warrant further study. For instance, while it is clear that advanced learners in the current sample were lower in behavioral aspects of self-regulation, it remains unclear whether this was a factor constraining their learning (e.g., difficulty remaining within the structures and sequences of the situation) or rather a hallmark of their manner of engagement in/with learning (e.g., convergent thinking, creativity). The current study thus represents a clarification and stimulus for further research into the nature of early learning and characteristics of highly effective early learners.

DATA AVAILABILITY STATEMENT

The dataset for this article is not publicly available because ethics approval was not sought or granted for such use. Requests to access the dataset should be directed to SH at stevenh@uow.edu.au.

ETHICS STATEMENT

This study was approved by the University of Wollongong's Human Research Ethics Committee, and participants were those who provided written parental consent and themselves provided verbal assent to participate.

AUTHOR CONTRIBUTIONS

SH conceptualized the study, secured funding for the study, oversaw data collection, analyzed the data, and led writing of the manuscript. EV aided in conceptualizing the study, managed the data collection and entry, and contributed to drafting of the manuscript.

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Reciprocal Filial Piety Facilitates Academic Success via Autonomy: Generalizing Findings in Chinese Society to a Global Context

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In cross-cultural psychology it is important to examine the universal (etic) and specific (emic) aspects of culture constructs. Filial piety is a core value of Chinese society that has shown related to psycho-social and academic development. This study was designed to investigate whether these relations revealed in specific cultural settings can be generalized to a global context. Using Chinese junior high school students as participants, Study 1 was intended to analyze the relations between filial piety and academic achievement, and whether autonomy need satisfaction serves as a bridge between them at the students' and classes' level. Study 2 was designed to examine whether these psycho-social and academic effects of filial piety can be applicable to a global context via analyzing two country-level databases [i.e., World Values Survey (WVS) and Program for International Student Assessment (PISA)]. The results of Study 1 showed that reciprocal filial piety was positively associated with academic achievement via the satisfaction of the need for autonomy, the authoritarian filial belief was negatively associated with academic achievement. The results of Study 2 showed that in a global context reciprocal filial belief in a society was related to the endorsement of autonomy, which in turn positively related to students' academic achievement in that society, while authoritarian filial belief did not show such effects. These findings suggest that some psychological constructs established in non-Western settings can also be applied to a global context.

Keywords: filial piety, autonomy, academic achievement, cross-culture, cultural universals

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INTRODUCTION

An important topic of cross-cultural study is whether psychological constructs established in Western cultures are applicable to non-Western settings (King and McInerney, 2014). In this study we went in the reverse direction. Specifically, the present study was intended to investigate whether the association between filial piety and academic achievement among Chinese students could be generalized to a global context. Filial piety is considered as a key virtue in Chinese society and other Confucian-heritage cultures (Hui et al., 2011; Cheah et al., 2018). For Chinese students academic success at schools is an important way to fulfill their filial beliefs (e.g., bring honor to the family).

Thus, we firstly used a Chinese sample to examine whether filial piety was associated with academic achievement via autonomy need satisfaction. Then we used country-level databases to investigate whether the relationships among these research variables could be generalized to a global context. This may provide new evidence showing the universal (etic) and specific (emic) aspects of cultural constructs, especially the ones established in non-Western settings (King and McInerney, 2014).

Filial Piety in Chinese Society

A salient feature of East Asian societies is a strong endorsement of filial piety, a value system stipulating children's obligations to their parents and family elders (Ho, 1996; Yeh, 2003; Guo et al., 2017). Adult children are required to prioritize the interests of the family over their own, and provide material and emotional support to their parents (Ho, 1996). According to Yeh and Bedford (2004), filial attitudes toward the parents include a sense of owing and submission (refers to as the authoritarian filial piety), and a sense of gratitude and love (refers to as the reciprocal filial piety). These two aspects of filial piety were characterized by distinct parent–child relationships (Fuligni and Zhang, 2004) that have different implications for children's psycho-social and academic development (Fuligni and Zhang, 2004; Pomerantz et al., 2011).

Specifically, reciprocal filial piety is characterized by natural intimate feelings and close relationships between parents and children, involving the benefaction of parents and gratitude of children (Yeh and Bedford, 2004). Children with reciprocal filial piety tend to repay their parents out of respect and love after they perceive parents' efforts, support, and sacrifice for them (Yeh and Bedford, 2004). Previous research has found that this aspect of filial piety was positively associated with harmonious interpersonal relationships, psycho-social and behavioral development (e.g., perspective taking, self-disclosure behavior), as well as positive-oriented personality traits (openness, agreeableness, and extroversion) (Yeh and Bedford, 2003).

While authoritarian filial piety emphasizes hierarchy and submission, entailing children's suppression of their needs in order to compliance with the family (Yeh and Bedford, 2004). Children are required to uphold honor for their families, take care of their parents, maintain family order, and continue family line by bearing male offspring. Obedience and indebtedness to parents are strongly emphasized because of their seniority. These characteristics of this aspect of filial piety usually lead to negative psychological outcomes (Yeh and Bedford, 2003), such as a higher level of depression, anxiety, and aggression (Yeh, 2006).

Beyond above-mentioned aspects, the academic effects of filial piety have also been investigated by previous researchers (Chen and Ho, 2012; Chen, 2016). As mentioned by Fuligni (2001), taking responsibility to family was an important source of motivation to study, especially for students from Asian families. Children tend to put more efforts on academic tasks when they view academic success as an important way to repay their parents, otherwise they may feel guilty (Fuligni, 2001). However, highly emphasizing honor for their family via academic achievement may also lead to unfavorable outcomes. For example, Ho (1996) suggested that authoritarian filial piety might lead to lower levels of creativity and cognitive inflexibility, which hindered academic achievement in the long run, in contrast, reciprocal filial piety generally related to positive-oriented development, such as flexible and resilient mindset, positive peer relationships at schools. Moreover, compared with less warm and coercive parent–child interactions that can lead to children's poor development in social and cognitive domains (Conger et al., 1995), intimate parent–child relationships which are associated with reciprocal filial piety have great effects on inspiring adolescents' involvement in academic tasks and facilitating better academic performance (Steinberg and Silk, 2002).

Filial Piety in a Global Context

Endorsement of filial attitudes toward the parents is not only an Asian heritage. It can be found everywhere in the world (Poskaitë, 2014). Actually, repaying parents because of their efforts and resources invested in their children is deeply embedded across various cultures (Jones et al., 2011). The Christian doctrine and the teachings of Islam both require the adherents to respect and love their parents (Dykstra and Fokkema, 2012). For example, in Christian tradition, a child's first obligation is to honor his/her father and mother. The Holy Bible says, "Listen to your father who gave your life, and don't despise your mother when she is old" (Proverbs 23:22). Devotion and loyalty to family are imperative for individuals in Latin American cultures, with the needs of the family usually prioritize over the needs of the individuals (Fuligni, 2001). Overall, though filial obligations are also endorsed by adult children in individualist cultures, such as take care of their older parents (Dykstra and Fokkema, 2012), filial norms to parents are more highly valued in collectivist cultures (Fuligni et al., 1999; Fuligni, 2001; Pomerantz et al., 2011).

The relations between filial responsibility and psycho-social outcomes have been investigated in many cultural settings. For example, using Latino and American samples, Fuligni (2001) found that a higher sense of filial responsibility was generally associated with more positive psychological outcomes, such as emotional and psychological well-being. Research using the American adolescents from the multicultural (including Asian, Latin American, and European) backgrounds also shows that adolescents endorsing filial beliefs are more likely to develop positive interpersonal (e.g., family and peer) relationships and achieve greater academic success (Fuligni et al., 1999; Fuligni, 2001). Pomerantz et al. (2011) also found that the sense of filial responsibility to parents was predictive of academic engagement and academic outcomes in adolescents from both Chinese and American cultural backgrounds.

Filial Beliefs, Autonomy, and Academic Achievement

The cultivation of autonomy has been strongly highlighted across different cultural settings given its promising benefits for individual's self-development (specifically for adolescents), such as psycho-social adjustment, well-being, and academic outcomes (Ryan and Deci, 2000a; Van Petegem et al., 2012; Tam, 2016). As many theorists propose, autonomy can be regarded as an

umbrella term including a wide range of psychological constructs, such as independence, self-endorsement, and agency (Beyers et al., 2003; Ryan et al., 2006), wherein independence and self-endorsement are now widely investigated in the literature (Van Petegem et al., 2012).

According to Self-Determination Theory (SDT; Ryan and Deci, 2000a), autonomy refers to volition or self-endorsement, individual with higher level of autonomy tend to feel that they are the master of their own destiny and life, and are more likely to actively engage in activities as their genuine interest and internal values rather than external pressure (Ryan and Deci, 2000a). Another important meaning of autonomy is independence, indicating the extent to which individual behave by themselves, which is opposed to rely on others (Smetana et al., 2004). Existing findings have indicated that the satisfaction of autonomy need can inspire individual's internal motivation for engaging into activities and advance their development (Ryan and Deci, 2000b).

The effects of autonomy on academic outcomes have been investigated by many researchers (Patrick et al., 1993; Peters et al., 2007; Diseth et al., 2012). Findings have indicated that the fulfillment of autonomy can positively predict academic achievement. The mechanism underlying this relation is that the satisfaction of autonomy benefits for inspiring students to engage into learning as their own pursuits and interest instead of external pressure. If the students have positive attitudes toward learning, they may take more efforts to overcome academic challenges thereby achieving desirable academic outcomes (Diseth et al., 2012). Similar findings also have shown that students who experience greater autonomy at schools are more likely to have positive emotions and place more efforts on academic tasks (Maralani et al., 2016; Gutiérrez and Tomás, 2019).

Previous research suggested that harmonious and supportive parent–child relationships could be one necessary precondition for cultivating autonomy (Hurst, 2010; Liu, 2013). Reciprocal filial piety, characterized by intimate feelings and close relationships between parents and children, is conductive to children's autonomy. Literature shows that close-knit relationship with parents is associated with children's a greater sense of belonging to their parents (Bao and Lam, 2008; Hui et al., 2011). Children live in this intimate parent–child relationship tend to perceive parental involvement (such as parental aspiration and expectations) as support and encouragement, and thus facilitate them transform parents' expectancy as personal goals and self-determination, which benefit for inspiring them actively engage into learning as pursuit of their own (Bao and Lam, 2008; Hui et al., 2011).

However, if children are socialized to suppress their needs in family interactions, and inhibit themselves to meet parents' requirement and social criterion, their need for autonomy is less likely to be fulfilled (Yeh, 2006). Children may feel out of control, incompetence, helplessness, and frustration in their daily life, resulting in weaker academic motivation and poorer academic performance (Ho, 1996). These findings suggest that reciprocal filial piety that is associated with the fulfillment of autonomy, but not authoritarian filial piety, may be conductive to better academic performance.

The Present Study

The main aim of this study is to investigate whether filial piety is associated with academic performance via autonomy need satisfaction, both in Chinese background and in a global context. In Study 1, we used Chinese junior high school students as participants. We constructed multilevel hierarchical linear modeling to examine the relations between filial beliefs, autonomy need satisfaction, and academic achievement at the students' and classes' level. Study 2 investigated the relationships among the above-mentioned variables using two open databases – the World Values Survey (WVS) and Program for International Student Assessment (PISA), which can be freely used by everyone. WVS contains items measuring filial obligation and the endorsement of autonomy at national level.

Filial piety includes two dimensions according to the model proposed by Yeh and Bedford (2003). According to the previous findings, we hypothesize that reciprocal filial belief can positively predict academic achievement, and this is true both in Chinese background (*hypothesis 1*) and in a global context (*hypothesis 2*). Authoritarian filial belief is not associated with academic achievement, and this is true both in Chinese background (*hypothesis 3*) and in a global context (*hypothesis 4*). In Study 1 autonomy need satisfaction was measured by a scale constructed by Deci and Ryan (2000) and Gagné (2003). Based on the existing findings, we hypothesize that in Chinese background the association between reciprocal filial piety and academic achievement can be explained by autonomy need satisfaction (*hypothesis 5*). Similarly, in Study 2 we hypothesize that the association between reciprocal filial piety and academic achievement at national level can be explained by the satisfaction of the need for autonomy (*hypothesis 6*).

Exploring the role of filial piety in facilitating academic performance is of great importance because enhancing family beliefs (especially reciprocal filial belief) may be an effective way to facilitate students' motivation to learn. And this is particularly valuable based on the increased reports suggest that a substantial gradual decrease of academic motivation has been observed during later childhood and early adolescent across different cultural backgrounds (Gottfried et al., 2009; Bugler et al., 2016).

STUDY 1

Participants

Participants of Study 1 were 750 junior high school students (381 girls, M_{age} = 13.08 years, SD_{age} = 1.20) randomly recruited from 15 classes of public middle schools in Eastern China. There were about 50 participants in each class. Among them 35.06% were from Grade 7, 34% were from Grade 8, and 30.93% were from Grade 9; 35% came from city/town, 34% came from countryside, the rest came from the suburbs; 61% of them were the only child in their native family. Written informed consent were obtained from all participants and their parents, participants were encouraged to complete these measures as their real beliefs.

Measures

Filial Beliefs

In Study 1, filial beliefs, including reciprocal filial belief and authoritarian filial belief, were measured by the Filial Piety Scale (FPS; Yeh and Bedford, 2003; Chen, 2014). FPS consists of 16 items using a 6-point scale ranging from 1 (extremely unimportant) to 6 (extremely important). The reciprocal filial belief dimension (e.g., be frequently concerned about my parents' general well-being) and the authoritarian filial belief dimension (e.g., taken my parents' suggestions even when I do not agree with them) each includes eight items. The total scores of all items of each dimension were taken to represent the levels of filial beliefs. FPS has showed acceptable reliability and validity in previous research using junior high students as participants (Yeh and Bedford, 2004). In this study, Cronbach's alpha for reciprocal and authoritarian filial beliefs were 0.81 and 0.74, respectively.

Autonomy Need

In Study 1, the Basic Psychological Needs Scale (BPNS; Gagné, 2003) was used to assess the satisfaction of the need for autonomy. The Chinese version of BPNS includes 21 items and has been proved to be a reliable and valid measure of Chinese middle school students' psychological needs (Zhen et al., 2017). In this study, the autonomy dimension was used to assess the satisfaction of the need for autonomy. A sample item is "I feel I am free to decide for myself how to live my life" (autonomy). Each item is rated on a 7-point scale (1 = strongly disagree, 7 = strongly agree). The total scores of all items were taken to represent the levels of autonomy. In this study, Cronbach's alpha was 0.70.

Academic Achievement

In Study 1, the participants' final grades in Reading, and Mathematics were obtained from school records. These scores can be used as valid measures of academic achievement (Chen et al., 2010). These scores were standardized according to grades, and were summed to create a total score of academic achievement.

Results

Correlation Analysis

Pearson's correlations among research variables were presented in **Table 1**. Reciprocal filial belief was positively and significantly associated with autonomy, and academic achievement, authoritarian filial belief was negatively associated with academic achievement. In addition, autonomy was also significantly associated with academic achievement.

TABLE 1 | Correlations between filial beliefs, autonomy, and academic achievement (Study 1).

	1	2	3	4
1. Reciprocal filial belief	–			
2. Authoritarian filial belief	0.26**	–		
3. Autonomy	0.07*	0.03	–	
4. Academic achievement	0.20**	−0.10**	0.10**	–

*$p < 0.05$, **$p < 0.01$.

Multilevel Hierarchical Linear Analysis

The multilevel hierarchical linear modelings were constructed using the HLM 6.08 software to examine the relations between reciprocal filial piety, autonomy, and academic achievement at students' and classes' levels. Firstly, to examine the relations between reciprocal filial piety, autonomy, and academic achievement at the students' level, we constructed model 1 (academic achievement = $\beta_0 + \beta_1$ reciprocal filial piety + β_2 autonomy + e_1) and model 2 (autonomy = $\beta_0 + \beta_1$ reciprocal filial piety + e_2). The models include dependent [academic achievement (model 1) and autonomy (model 2)] and independent variables [reciprocal filial piety and autonomy (model 1) and reciprocal filial piety (model 2)], intercept (β_0), slope (β_1 and β_2), and error (e_1 and e_2).

The results showed that reciprocal filial piety and autonomy significantly predicted academic achievement (model 1); moreover, reciprocal filial piety also significantly predicted autonomy (model 2), suggesting that reciprocal filial piety can positively predict academic achievement via autonomy (**Table 2**). In addition, following the same procedure, the results also indicated that the authoritarian filial piety negatively predicted academic achievement ($\beta = -0.02$, $t = -2.76$, $p < 0.05$), the relation between the authoritarian filial piety and autonomy was not significant ($\beta = 0.02$, $t = 0.72$, $p > 0.05$).

Then, to examine the relations between reciprocal filial piety, autonomy, and academic achievement at the classes' level, we constructed model 3 ($\beta_0 = \gamma_{00} + \gamma_{01}$ class + r_1) and model 4 ($\beta_1 = \gamma_{10} + \gamma_{11}$ class + r_2) based on model 1 and model 2, separately. The models examine the extent that class variable affects the above-mentioned variables. The results indicated that class variable did not interfere the relations between reciprocal filial piety ($\beta = -0.00$, $t = -0.20$, $p > 0.05$), autonomy ($\beta = 0.00$, $t = 0.06$, $p > 0.05$), and academic achievement. In addition, class variable also did not interfere the relation between reciprocal filial piety ($\beta = 0.00$, $t = 0.35$, $p > 0.05$) and autonomy. Finally, the results showed that the relations between the authoritarian filial piety, autonomy, and academic achievement were all not significant ($p_S > 0.05$).

At the first level, the 95% bias-corrected bootstrap confidence interval did not include zero when reciprocal filial piety was the predictor and academic achievement was the outcome variable [$CI_{directpath}$: (0.019, 0.040); $CI_{indirectpath(viaautonomy)}$: (0.001, 0.003)], in addition, the direct pathway from the

TABLE 2 | The multilevel hierarchical linear analytical results without the second level variables.

Models	Independent variables	Dependent variables	Coefficient and significance		
			Coefficient	Error	*t*
Model 1	RFP	Academic achievement	0.03	0.00	5.32***
	Autonomy		0.02	0.00	2.39***
Model 2	RFP	Autonomy	0.06	0.03	1.99*

*$p < 0.05$, ***$p < 0.001$.

authoritarian filial piety to academic achievement also did not include zero [CI: (−0.029, −0.005)].

Additionally, the relationships between reciprocal filial belief, autonomy, and academic achievement were also examined through constructing the SEM (see **Figure 1**). The path model fit the data well (χ^2/df = 1.73, NFI = 0.95, CFI = 0.98, TLI = 0.97, RMSEA = 0.03). Authoritarian filial belief was not significantly associated with autonomy need satisfaction and academic achievement, and therefore the results were not be represented in **Figure 1** (Zhao et al., 2010).

STUDY 2

Participants

Participants of Study 2 were taken from WVS[1] and PISA[2]. WVS, which has been conducted by the Executive Committee of the WVS Association since 1981, is a global research program focusing on human values and beliefs, such as politics importance, religion importance, and importance of equalizing chances for education. The WVS has been conducted six waves. Data were collected via random sampling method from nearly 100 countries/regions, representing 90% of the adult (18 years and older) population of the world. We used the participants who have finished the measures of this study. The date information of study 2 has been presented in the **Appendix**.

Program for International Student Assessment is a global academic assessment program aiming to test whether the adolescents have mastered the required knowledge and skills through a series of test, including Mathematics, Reading, and Science/Problem-solving examinations (Jerrim, 2015). PISA has been conducted by the Organization for Economic Co-operation and Development (OECD) in more than 60 countries/regions every 3 years since 2000. During the investigation, OECD randomly selected 4500–10,000 teenagers (15–16 years old) who were from different family backgrounds in each country. Additionally, a series of variables that reflect national-level economic, social, and population development were controlled in this study, including GDPpc[3], HDI[4], total fertility (live births per woman)[5], and population density (see text footnote 3).

Measures

Filial Beliefs

In Study 2, a FPS was constructed according to the definition of Yeh and Bedford (2003). The item in WVS "Respect and love for parents" (A025; 1 = always respect, 3 = neither) was used to measure reciprocal filial belief. This item parallels the one "grateful to my parents for raising me" in the reciprocity sub-scale of the FPS (Yeh, 2003; Chen, 2014). Dummy-variable method was used to translate this categorical variable into the continuous variable before into the regression analysis (Balestra, 2008). Another item "One of main goals in life has been to make my parents proud" (D054; 1 = agree strongly, 4 = strongly disagree) was used to measure authoritarian filial belief. This item parallels the one "meet my parents' expectations" in the authoritarian sub-scale of the FPS (Yeh, 2003; Chen, 2014). These items were reverse-scored in order that higher scores indicate

[1]http://www.worldvaluessurvey.org
[2]http://www.oecd.org/pisa/keyfindings/
[3]http://data.worldbank.org
[4]http://hdr.undp.org
[5]https://population.un.org

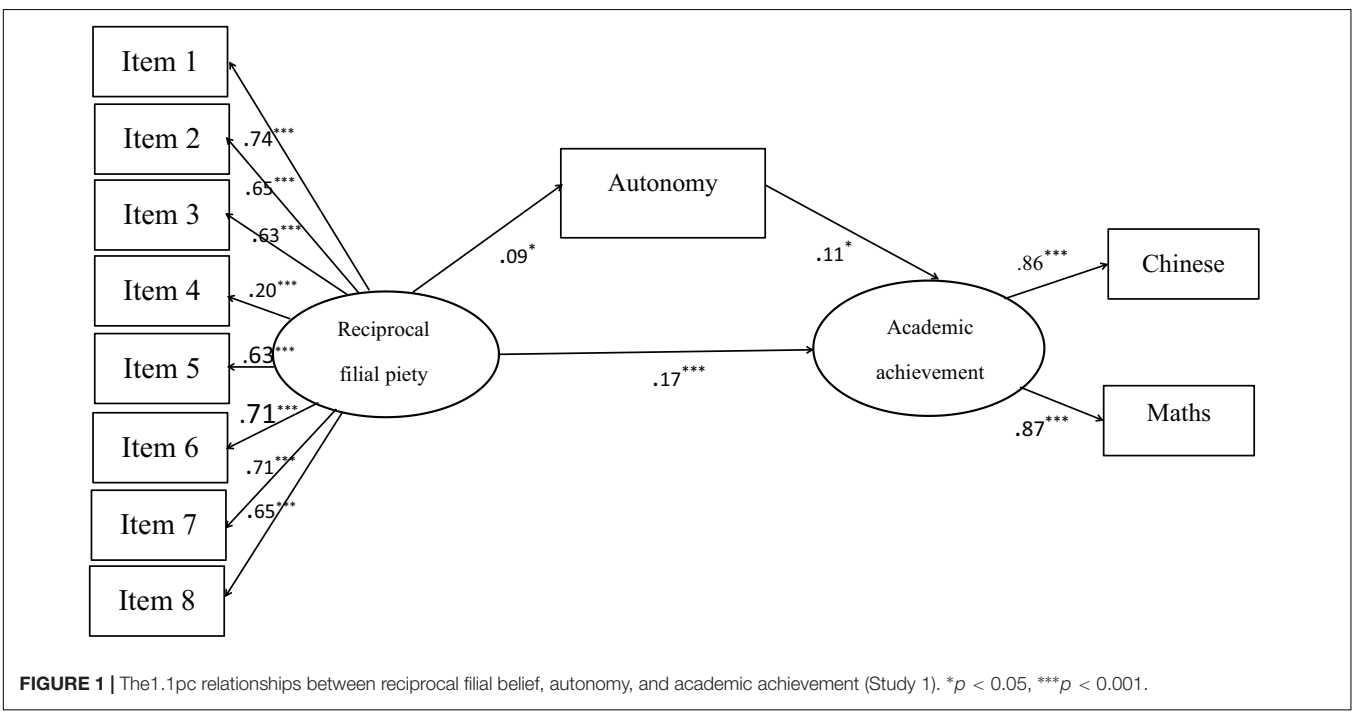

FIGURE 1 | The1.1pc relationships between reciprocal filial belief, autonomy, and academic achievement (Study 1). *$p < 0.05$, ***$p < 0.001$.

higher levels of reciprocal and authoritarian filial belief. Filial piety scores in each country/region were acquired by averaging the scores of all participants within that country/region.

Autonomy

In Study 2 the need for autonomy was indicated by the Autonomy Index in WVS (0 = obedience, 4 = determination/independence). The Autonomy Index comprises four binary choice items (0 = unmentioned, 1 = important), two positively worded (i.e., independence, determination) and two negatively worded (i.e., religious faith, obedience). It reflects how strongly independence and non-obedience are encouraged in a society. All participants were aggregated according to country/region, and the mean score of this item was used as an indicator of the satisfaction of the need for autonomy of each country/region. At national level Cronbach's alpha of this measure is 0.75.

Academic Achievement

In Study 2, to chronologically match the six wave of WVS that was conducted since 1981, PISA scores of the last three waves (2009, 2012, and 2015) were used in this study. Reading and Mathematics scores were separately averaged and standardized according to countries/regions and waves, and eventually summed up as a final score of academic achievement at national level. GDP_{pc} (we used the data collected during 2010–2014), HDI (we used the data collected during 2013–2015), total fertility (live births per woman; we used the data collected during 2010–2015), and population density (we used the data collected in 2012) were used as controls in this study.

Results

Correlation Analysis

Pearson's correlations among research variables were presented in **Table 3**. The results showed that reciprocal filial belief was positively and significantly correlated with autonomy and academic achievement, and autonomy was significantly correlated with academic achievement, while authoritarian filial belief was not significantly associated with autonomy and academic achievement.

Mediation Analysis

Mediation analysis was carried out to examine the role of autonomy in the relationship between reciprocal filial belief and academic achievement. Reciprocal filial belief and autonomy were defined as observed variables, and academic achievement (measured by Reading and Mathematics) was defined as a latent variable (**Figure 2**).

TABLE 3 | Correlations between filial beliefs, autonomy, and academic achievement (Study 2).

	1	2	3	4
1. Reciprocal filial belief	–			
2. Authoritarian filial belief	0.14	–		
3. Autonomy	0.25*	0.11	–	
4. Academic achievement	0.37**	−0.07	0.34**	–

*$p < 0.05$, **$p < 0.01$.

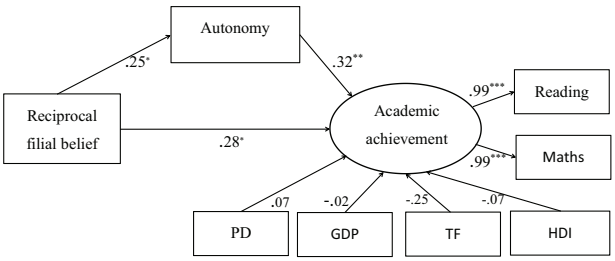

FIGURE 2 | The relationships between reciprocal filial belief, autonomy, and academic achievement (Study 2). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. PD, population density; TF, total fertility (live births per woman); HDI, human development index.

The model fit the data well (χ^2/df = 1.08, NFI = 0.95, CFI = 1.00, TLI = 0.99, RMSEA = 0.04). In **Figure 2**, reciprocal filial belief was significantly associated with autonomy, and autonomy was significantly associated with academic achievement after control variables were added to the model. The direct relation between reciprocal filial belief and academic achievement was also significant. The paths from control variables to academic achievement were all insignificant ($ps > 0.05$). The estimated mediating effect was 0.08, explaining 22.22% of the total effect (0.36) of reciprocal filial belief on academic achievement. The effects of authoritarian filial piety on autonomy and academic achievement were not significant ($ps > 0.05$).

We constructed bootstrap confidence intervals to test specific mediation and direct pathways in structural equation models. The 95% bias-corrected bootstrap confidence interval both did not contain zero when reciprocal filial piety was the predictor ($CI_{directpath}$: 2.11–17.43; $CI_{indirectpath(viaautonomy)}$: 0.01–6.53), while the 95% bias-corrected bootstrap confidence interval both contained zero when authoritarian filial piety was the predictor ($CI_{directpath}$: −3.31–1.34; $CI_{indirectpath(viaautonomy)}$: −0.28–3.24).

DISCUSSION

Filial Beliefs, Autonomy, and Academic Achievement

In consistence with hypothesis 1, this study found that reciprocal filial belief can positively predicted Chinese adolescents' academic achievement. This relationship still holds at national level, showing that a respectful and loving attitude toward the parents has positive implications for facilitating adolescents' academic achievement at national level. Therefore, *hypothesis 2* was also supported. Difference from hypothesis 3, this study found that Chinese adolescents' authoritarian filial belief was negatively and significantly associated with their academic achievement. In a global context, the results showed that a stronger endorsement of authoritarian filial piety in a country was not associated with adolescents' higher levels of academic achievement in that country. Therefore, *hypothesis 4* was supported.

The results from this study indicated a positive and significant association between reciprocal filial piety and academic achievement both in Chinese society and in a global context. These findings highlight the importance of positive parent–child relationship that related to reciprocal filial piety in facilitating children's psycho-social and academic development, suggesting that students who develop family obligations based on the reciprocity are more likely to obtain desirable academic outcomes (Leung and Zhang, 2000).

Our results also indicated that a general negative association between authoritarian filial piety and academic achievement both in Chinese society and in a global context. These findings suggest that if children are required to suppress their needs and feelings to meet their parents' requirement and social criterion, their psycho-social and academic development are more likely to be hindered. This happen could be due to the fact that when children are demanded to repay their parents out of obedience and indebtedness (opposed to love and intimate affections), they tend to experience more negative emotions, such as a sense of losing control, incompetence, helplessness, and frustration, which hinder them from making positive-oriented changes (Yeh and Bedford, 2004).

In consistence with *hypothesis 5* and *hypothesis 6*, the results in this study also indicated that reciprocal filial piety was positively associated with the satisfaction of the need for autonomy, which in turn contributed to academic achievement both at individual level and at national level. This could be due to the harmonious parent–child relationship that related to reciprocal filial piety facilitates the fulfillment of autonomy and provides necessary nourishment for inspiring children to learn. For example, when parents encourage children's active participation, acknowledge children's perspectives, and provide social rewards for positive behaviors, children can naturally generate gratitude for their parents' efforts and support, the expectations from parents in this close-knit family interaction process are more likely to be internalized as self-volition by children, inspiring them greater engagement into learning activities without experiencing external pressure or demands (Bao and Lam, 2008; Vasquez et al., 2016).

These results of this study have revealed culturally universal (i.e., etic) findings. Specifically, these findings are that: (1) Endorsing reciprocal filial piety in a society is beneficial for students' academic development in that society, while endorsing authoritarian filial piety in a society does not have such effects. (2) The association between reciprocal filial piety and students' academic development can be partly accounted by autonomy need satisfaction, and this is a universal finding across different cultural backgrounds.

Strengths, Limitations, and Implications

This study throws new light on exploring the universal and specific aspects of psychological constructs. These findings in this study imply that filial beliefs established in non-Western settings can also be applied to a global context. The universality of filial piety may be the result of kin selection, an evolutionary strategy favoring reproductive success of relatives (Guo et al., 2017).

Nevertheless, some limitations of this study should be addressed. First, the participants and measures used in Study 1 and Study 2 were not equivalent. The participants in Study 1 were junior high school students, whereas the participants in Study 2 were samples from the population of 15 years and older. However, cultural values (e.g., filial beliefs, endorsement of personal autonomy) are broadly shared by various members in a society. So we assumed that the students' attitudes toward filial piety can be reflected in other populations. Second, in Study 1 filial piety was measured by a scale with satisfying reliability and validity, while in Study 2 reciprocal and authoritarian filial piety were separately measured by only one item. Although one-item scale has been widely used in social surveys (Nevitte and Cochrane, 2006), whether these items can measure the target constructs is still a question. Furthermore, the autonomy index used in Study 2 indicated how strongly self-determination or independence (vs. obedience) was endorsed in a society, and we proposed that in a society where autonomy was strongly endorsed, the need for autonomy was more likely to be satisfied, whereas more direct evidence was needed to support this proposition. Third, the correlational study design of this study limits its power to infer causalities between research variables. Future researchers are encouraged to manipulate filial beliefs to examine their effects on academic performance. Fourth, in Chinese culture, individuating and relating autonomy may play different roles in motivating learning (Yeh and Yang, 2006; Yeh et al., 2009; Chen et al., 2013). The contribution of different forms of autonomy to academic success can be a meaningful theme that deserves to be investigated in the future research. Fifth, filial ideas endorsed by individual can also interact with other external factors and exert influence on academic achievement, future investigations can clarify the relations among these variables via advanced statistical methods (e.g., multilevel modeling). Last but not least, the results in this study showed that autonomy psychological need can partly mediate the association between filial piety and academic achievement, implying the existence of other mediators in this pathway, which are encouraged to be examined by future researchers.

This study highlights the role of family obligations in facilitating students' academic achievement. This is particularly important because recently there is a decline in academic motivation during later childhood and early adolescent (Bugler et al., 2016). Family is the first agenda of socialization, to cultivate children's family obligations, an authoritative parenting style rather than an authoritarian parenting style should be adopted by the parents. Parents should be more kind, loving, and caring to their children, the warm parenting style facilitates children repay to their parents with the same positive emotions, expectations from parents can be more easily to be internalized as self-pursuit rather than extra requirements by their children in the harmonious family interaction, which benefit for children's academic engagement and performance.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://www.cafonline.org.

ETHICS STATEMENT

This study was carried out on the basis of the Declaration of Helsinki, and was conducted under the approval of the Institutional Review Board (IRB) at Shandong Normal University. Written informed consent was obtained from all participants before conducting the research, this study had also got the approval of volunteer participants' guardians. This study caused no harm to participants' physical and mental health.

AUTHOR CONTRIBUTIONS

JZ and QG designed the research, wrote, and revised the manuscript. RX and JZ collected and analyzed the data. All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00069/full#supplementary-material

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The Supporting Role of Mentees' Peers in Online Mentoring: A Longitudinal Social Network Analysis of Peer Influence

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Studies show that online mentoring is an effective measure to support girls in STEM (science, technology, engineering, and mathematics), especially if it also allows for networking with other participants on the mentoring platform. However, research is missing on peer influence. This topic seems especially crucial in programs for adolescents as peer influence plays an important role at this age. In our study, we investigated peer influence on mentoring outcomes – confidence in own STEM abilities and STEM-related activities – in an online mentoring program in STEM for secondary school girls (N = 124, M = 14.3 years, SD = 2.2 years, age range: 11–19 years). The program provides girls with at least 1 year of one-on-one interaction with a personal female mentor who has a college degree in a STEM subject. Participants can also interact with other participants on the platform. We used a longitudinal social network analysis approach to examine peer influence on mentoring outcomes. Our results indicate that both mentoring outcomes – mentees' confidence in own STEM abilities and STEM-related activities – are influenced by peers moderated by the mentees' own age. Younger mentees tended to become more similar to their peers regarding confidence in own STEM abilities and STEM-related activities, whereas older mentees tended to become more dissimilar over time. In addition, peer group size had a positive effect on confidence in own STEM abilities, but not on STEM-related activities. This effect was moderated by the mentee's age. Overall, peers have a positive influence on the measured mentoring outcomes, especially for young mentees.

Keywords: online mentoring, peer influence, social network analysis, RSiena, STEM

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INTRODUCTION

In Germany and many other industrial countries, the participation rate of females in STEM (science, technology, engineering and mathematics) is deficient, especially in engineering and computer-science (Statistisches Bundesamt, 2018). For example, only about one in five STEM academics, and about one out of nine STEM skilled labors is female. There are several external reasons why this discrepancy occurs. Some argue that one possible reason for this decline relates to negative stereotypes about STEM fields (e.g., Kessels et al., 2006), such as the stereotype that women working in the STEM field are unfeminine (Yoder and Schleicher, 1996; Smeding, 2012).

These pervasive stereotypes negatively impact attitudes toward STEM, competence beliefs, and career preferences for females (e.g., Steffens et al., 2010; Nosek and Smyth, 2011; Cundiff et al., 2013). This gender discrepancy starts early. Studies have demonstrated that students' interest in STEM subjects decreases throughout their school careers (Frenzel et al., 2010), indicating that interventions aimed at encouraging STEM involvement should begin during school years while students are still forming their decisions.

An effective measure to change the situation is mentoring (e.g., McCord et al., 2009; Stoeger et al., 2013). It combines various advantages. For example, mentors can answer mentees' questions about STEM, discuss interesting STEM topics and work on STEM projects with their mentees, all of which have a positive influence on mentees' self-confidence, STEM-related activities, and STEM interest (Harsh et al., 2011; Schultz et al., 2011). That female mentors also act as role models plays an especially important role when it comes to supporting girls in STEM (Eccles, 1984). Online mentoring, too, is notably advantageous (Stoeger et al., 2013, 2016). Because of its time and local flexibility, online mentoring enables to include extensive numbers of female mentors and mentees (who due to the low participation rates in STEM cannot be easily found for offline programs) – and thereby offers networking opportunities with both female high-status role models (mentors) as well as female peer role models (mentees). Studies outside the field of mentoring indicate that same-age role models are particularly effective in changing the perception of STEM fields as unfeminine (Kessels et al., 2014) and can act as social vaccines who inoculate girls against negative influences on their STEM self-concepts (Dasgupta, 2011; Stout et al., 2011; Dennehy and Dasgupta, 2017). Research within the field of mentoring shows that online-mentoring that combines one-on-one mentoring with networking with same-age role models is more effective than one-on-one mentoring (Stoeger et al., 2017). However, to the best of our knowledge there is no research on peer influences in the context of online mentoring for girls in STEM, which is unfortunate as especially during adolescence, peer influence becomes particularly important (DeLay et al., 2016).

The main objective of this study is to investigate whether mentoring outcomes (namely confidence in own STEM abilities and STEM-related activities) of mentees are influenced by networking with other mentees (peer influence). As research shows that peer influence differs during development (e.g., Steinberg and Monahan, 2007), we also investigate the moderating role of age when it comes to peer influence on mentoring outcomes. Furthermore, we consider that the contributing role of the size of a mentee's peer group (as indicated by e.g., Wang et al., 2016) might impact mentoring outcomes.

Online Mentoring for Girls in STEM

Girls show a lower interest in STEM compared to boys and report lower self-confidence in their own STEM abilities (Hoffmann, 2002; Litzler et al., 2014; Ellis et al., 2016; e.g., Cheryan et al., 2017; Hand et al., 2017), which in turn can lead to reduced involvement in STEM-related activities (e.g., Shrauger and Schohn, 1995). Mentoring offers a good opportunity for extracurricular intervention. Mentoring is commonly defined as a relatively stable dyadic relationship between an experienced mentor and his or her less experienced mentee. It is characterized by mutual trust and goodwill, and it aims to promote learning and development as well as the mentee's progress (Ziegler, 2009). In mentoring programs for girls in STEM, most often female, higher status, and older role models act as mentors (Pleiss and Feldhusen, 1995; Khare et al., 2013; e.g., Dawson et al., 2015). In online mentoring programs for girls in STEM, one-on-one mentoring sometimes is complemented by networking opportunities with other mentees and mentors that are similarly interested in STEM (Stoeger et al., 2016, 2017). Research shows that these networking opportunities can lead to better outcomes than one-on-one mentoring alone (Stoeger et al., 2016, 2017). One can only speculate about the reasons for the higher effectiveness of a combination of one-on-one mentoring and networking opportunities in online mentoring for girls in STEM. First, the increased number of communication partners seems to lead to more STEM communication and more STEM-related activities (Stoeger et al., 2016, 2017). Second, the specific influence of peers might also play a role. In addition to female higher status role models, programs of this kind also offer peers as role models, which seems to have an especially big influence on the development of STEM self-concept (Dasgupta, 2011) and STEM elective behavior in female students (Dasgupta and Stout, 2014). So far, there is little research on peer influence in online mentoring in STEM.

Peer Influence in Online Mentoring

Due to the relatively low interest of girls in STEM and its continual decrease during school time (Gardner, 1985; Hoffmann et al., 1985; Kerr and Robinson Kurpius, 2004), it is difficult for girls interested in STEM to find female peers with a similar STEM interest. This is problematic because peers act as role models and as a comparison level when it comes to abilities and behavior (Schunk, 1987, 1989). In contexts where objective standards of behavior are unclear or unavailable – as is the case for STEM subjects for girls due to missing female role models – peers are better role models than grownups; most effective are peers who have a similar or slightly higher experience or status (Schunk, 1987). Same-age female role models are particularly effective in changing the perception of STEM fields as unfeminine (Kessels et al., 2014) and peer support plays an important role in girls' willingness to persist in STEM (Schoon and Eccles, 2014). Peer networks offer opportunities for interaction, observation of others, and facilitate access to activities (Dweck and Goetz, 1978). Furthermore, peers can positively influence self-efficacy (especially when less pronounced, see Schunk, 1989), which seems to be important for girls in STEM as they often do not dare to choose STEM, even if their achievements are high (Eccles, 1994). Peer mentoring makes use of the positive influence that peers can have on a wide range of mentoring objectives (Colvin and Ashman, 2010; Karcher, 2013).

Through online mentoring, girls interested in STEM can get access to a social environment where their STEM interest is valued, and they can meet (sometimes for the first time) a large number of other girls and women who are similarly

interested in STEM. Social learning theories (Zimbardo and Leippe, 1991) suggest that this change in the social environment – especially through peer influence – can lead to changes in their own behavior and values (i.e., mentoring outcomes). However, most research examines peer influence in offline contexts, e.g., the classroom, where students physically interact and see the actions of each other. In these contexts, it could be demonstrated that peers influence each other in various ways (Steinberg and Silverberg, 1986; prosocial behavior, Wentzel et al., 2004; smoking, Mercken et al., 2010; e.g., delinquent behavior, Kerr et al., 2012). For some time, it was doubted that a similar influence can be found in online contexts. It was assumed that due to missing physical contact and therefore missing facial expressions and gesture in computer-based communication, emotional and observational information gets lost that is important for peer influence. However, it is now known that with the help of Emoji usage and image-based communication, a proxy for "real" interaction can be achieved (e.g., Kralj Novak et al., 2015). Indeed, several studies from different fields have shown evidence of peer influence in online (social) networks (Hui and Buchegger, 2009; Aral and Walker, 2011, 2012; Lewis et al., 2012; Huang et al., 2014; Bapna and Umyarov, 2015). Moreover, the current state of research shows clear indications of moderation of age on peer influence (in online settings). In addition, peer network size plays a role in peer influence. This will be discussed in more detail in the next two sections.

Age as a Moderator of Peer Influence

Peer influence seems to be important to differing degrees in various stages of development (Brechwald and Prinstein, 2011). Studies have demonstrated that individuals appear more likely to be influenced by their peers in earlier developmental stages of adolescence than in later stages (e.g., Steinberg and Monahan, 2007; Aral and Walker, 2012). Again, most studies have been conducted in offline contexts. For example in a sample of over 3600 individuals ranging in age from 10 to 30 years, a negative linear relationship between age and peer influence was found (Steinberg and Monahan, 2007). Peer influence decreased steadily, particularly in individuals aged between 14 and 18 years. Similar results have also been found in earlier works by Steinberg et al. (1997). These results are consistent with the effects of "cross-mentoring," in which older adolescents act as mentors for younger teenagers. For example, cross-mentoring can help develop self−esteem, social skills, and behavioral competence in mentees (Karcher, 2005).

While so far, no research exists on age effects of peer influence in online mentoring, studies in online contexts suggest similar results for this area. For example, Aral and Walker (2012) showed that younger users were more susceptible to peer influence than older ones when it came to Facebook applications. Bapna and Umyarov (2015) also found that younger Facebook users were more influenced by their Facebook peers than older ones.

Peer Group Size as a Contributing Factor

Another aspect that might contribute to the peer influence on mentoring outcomes in online mentoring is the size of the online peer group mentees interact with on the mentoring platform. On online mentoring platforms, a mentee can potentially interact (via messaging tools) with a varying number of other mentees. Research from offline context indicates that the larger the peer group an individual interacts with, the more pronounced the peer influence (e.g., Wang et al., 2016). An explanation for this might be a kind of "contagiousness." Similar to disease infections – where it is evident that the more people an individual has contact with, the more likely he or she will become infected with a contagious disease (Ferrari et al., 2006) – interacting with a large number of peers with similar values, interests, and behaviors is more likely to lead to an adaption of the same values, interests, and behaviors. In the offline context, there is ample evidence of "contagiousness" for various attributes, values, and behaviors (obesity, Christakis and Fowler, 2007; e.g., delinquent behavior, Burk et al., 2008; Dijkstra et al., 2010; smoking, Mercken et al., 2010; depression, Schaefer et al., 2011; tastes in books, films, and movies, Lewis et al., 2012). For the online mentoring context, this might translate to: the more conversational partners a mentee has on the mentoring platform, the more likely the mentee will be influenced by his or her peers and thus, adopt their level of confidence in own STEM abilities or STEM-related activities.

The Present Study

There is ample evidence that online mentoring is an effective measure in the support of girls in STEM. An advantage of online mentoring programs is that girls not only profit from an individual mentor – in many cases an adult, high status, female role model – but that they can also interact with many other girls (and women) interested in STEM. Although there is a lack of research on peer influence in the context of online mentoring, based on research on peer influence from offline contexts, as well as from online contexts unrelated to mentoring, we expect that peer influence affects mentoring outcomes. Research from the offline context shows that peers influence (STEM-related) self-concept (Schunk, 1989; Dasgupta, 2011) and activities (Dasgupta and Stout, 2014). Thus, our first hypothesis is:

Hypothesis 1: Mentees are subject to peer influence in online mentoring, regarding (H1a) confidence in own STEM abilities and (H1b) STEM-related activities.

We test this hypothesis in the following way: If peer influence is present, a random mentee's value of confidence in own STEM abilities and STEM-related activities over time should approach the (average) value of her peer group. To obtain evidence for this hypothesis and the following hypotheses, we used a longitudinal social network analysis approach. Here, the two main elements are the mentees and their peer relationships. In the method we applied, the evolution of the peer relationship network as well as its influence on the mentoring outcomes are considered simultaneously. The driving effects of this co-evolution are represented by log-odds values. A more detailed introduction to network analysis and the method used herein can be found in section "A Primer of Longitudinal Social Network Analysis." A positive, significant value of the corresponding peer influence effect would support hypothesis 1.

Research suggests that peer influence effects are moderated by age. Both studies from the offline context (Steinberg and Monahan, 2007; Aral and Walker, 2012) as well as from the online

context – unrelated to online mentoring (Aral and Walker, 2012; Bapna and Umyarov, 2015) – suggest that younger individuals are more likely to be influenced by their peers than older individuals. Thus, our second hypothesis is:

Hypothesis 2: The mentee's age moderates the peer influence that a mentee is subject to in the following way: younger mentees are more susceptible to peer influence (than older mentees) in both (H2a) their confidence in STEM abilities and (H2b) their STEM-related activities.

To test hypothesis 2, we included a moderation term of age on the respective peer influence effect. A negative, significant value of the corresponding effect would support our hypothesis.

Another aspect that might contribute to mentoring success is the size of the peer group. The role of peer group size has been demonstrated for various attributes, values, and behaviors in the offline context (Christakis and Fowler, 2007; Burk et al., 2008; Mercken et al., 2010; Schaefer et al., 2011; Lewis et al., 2012; Wang et al., 2016). Based on these findings, we assume that the larger the online peer group of a mentee (i.e., the number of peer mentees an individual interacts with on the online mentoring platform), the more positive the mentoring outcomes. Thus, our third hypothesis is:

Hypothesis 3: The size of the peer group (operationalized by the number of peers that regularly send messages to the mentee) contributes positively to the mentoring outcomes in the following way: The larger the size of the peer group a mentee interacts with, the more positive the development of her (H3a) confidence in own STEM abilities and (H3b) STEM-related activities.

A significantly positive value of the corresponding peer group size effect would support hypothesis 3. Similar to the influence of the peers on mentoring outcomes, the influence of the peer group size on the mentoring outcomes might also be moderated by the age of the specific mentee (Steinberg and Monahan, 2007; Brechwald and Prinstein, 2011). Thus, our fourth hypothesis is:

Hypothesis 4: The influence of the size of the peer group (operationalized by the number of peers that regularly send messages to the mentee) on the mentoring outcomes is moderated by the mentee's age in the following way: The older mentees are, the less they benefit from an increasing size of their peer group regarding (H4a) their confidence in STEM abilities and (H4b) their STEM-related activities.

To address hypothesis 4, we included a moderation term of age on the peer group size effect of hypothesis 3. In our applied method, a negative, significant value of the corresponding effect would support hypothesis 4.

MATERIALS AND METHODS

A Primer of Longitudinal Social Network Analysis

The communication data between mentees and mentors in online mentoring (e.g., emails and chat messages) can be used to create social networks. In these networks, mentees and mentors are called nodes or vertices, the communication paths between the persons are called ties or edges. If, for example, two mentees exchange messages with each other, a new edge is created between these two nodes. During the mentoring process, new edges are created, and old ones are dissolved. Because of these networking activities (creation of new edges and dissolvement of existing edges) the individual mentees do not develop independently of each other, which leads to (statistical) interdependence in the sample. This dependency contrasts with the assumption of the independence of many statistical methods (e.g., linear regression). Modeling and analyzing changing networks and mentee attributes (i.e., mentoring outcomes) require alternative statistical methods. For this reason, we analyzed our data with the help of stochastic actor-oriented modeling, implemented in the R package RSiena (R Core Team, 2017; Ripley et al., 2018). Modeling peer influence without taking the changing network structure into account can lead to incorrect results (Aral et al., 2009; Steglich et al., 2010; Shalizi and Thomas, 2011). Thus, longitudinal network analyses (in our case a stochastic actor oriented model) are used to get a clearer idea about the co-evolution of measured attributes (in our case mentees' confidence in own STEM abilities and STEM-related activities) and social networks (in our case peer networks). In this context, two main driving forces must be differentiated: *selection* and *influence*.

Selection and Influence

The term *selection* describes that individuals consciously (de-)select their peers based on certain criteria, in many cases – especially during adolescence – based on similarity concerning demographic attributes, such as age, gender and ethnicity (e.g., Kupersmidt et al., 1995). In online mentoring for STEM interested girls, for example, similar age is expected to be one driving factor for the creation of new edges between mentees. This effect is also known under the term homophily and is not only restricted to demographic variables, but also includes non-demographic attributes like attending the same school class (McPherson et al., 2001). In our online mentoring context, a non-demographic attribute would be the affiliation to "mentoring groups" of two mentors and two mentees on the platform (for a detailed description refer to section "Measures").

The term *influence* describes the effect that peers can have on certain attributes of an individual (in our case mentoring outcomes). This means that the peer network mentees interact with might affect their mentoring outcomes (influence).

It is important to mention that within social networks (and in our case the peer networks of mentees) selection and influence processes take place simultaneously and are interwoven (Steglich et al., 2010; Shalizi and Thomas, 2011). Thus, for a better understanding of the processes, it is necessary to disentangle influence from selection.

Disentangling Selection From Influence

Network (and other) data are usually not collected continuously, but in (one or more) snapshots, often referred to as "waves." When we examine a snapshot of a social network and look at one dyad of peer-mentees (i.e., the smallest social group of two connected mentees), the following problem can arise: If two peer-mentees share the same behavior or attribute, we cannot tell whether this similarity arose because of (1) *selection* or (2) *influence* (provided that this behavior or attribute is changeable).

(1) Similarity arose due to *selection* if mentee A and mentee B already shared the same behavior or attribute (in our case confidence in own STEM abilities and STEM-related activities) before the start of their peer relationship and chose to interact with each other as peers because of this similarity. (2) Similarity arose due to *influence* if mentees A and B shared a different expression in a behavior or attribute (in our case confidence in own STEM abilities and STEM-related activities) before forming their peer relationship. However, through the established peer relationship one mentee's behavior or attribute spread to her peer and therefore changed her attribute. Note that in this example, we only speak of "positive influence," i.e., an influence in which both participants end up with the more similar behavior or attributes. Opposing effects can also occur so that the behavior or attributes become more dissimilar.

Thus, in order to examine peer influence regarding our mentoring outcome variables (i.e., confidence in own STEM abilities and STEM-related activities), it is necessary to simultaneously consider whether these variables affect the development of the peer relationship network (i.e., whether, for example, mentees with high confidence tend to establish more peer relationships than mentees with low confidence). RSiena addresses the mentioned issues and some further peculiarities of longitudinal network data (Snijders, 2001, 2017; Snijders et al., 2010; Ripley et al., 2018).

Main Data Analysis Method: RSiena – A Stochastic Actor-Oriented Model

RSiena stands for the R-package Simulation Investigation for Empirical Network Analysis (Ripley et al., 2018). This stochastic actor-oriented model considers the interplay between selection and influence, and controls for other confounding variables. In the RSiena model, both mentees' peer relationships and mentoring outcome variables are assumed to change continuously between (the two) measurement points (T1 and T2). Those changes are decomposed into small sequential steps, so-called *ministeps*, in which mentees can change their peer relationships or their respective mentoring outcome variable (Snijders et al., 2010; Ripley et al., 2018). With these ministeps, the goal is to simulate the unobserved changes of the peer relationship network (including all attributes of the mentees) from the first measurement time (i.e., beginning of mentoring) to the second measurement time (i.e., after half a year of mentoring). In each ministep of the simulation, a random mentee is given a "decision opportunity" where she probabilistically changes either her peer relationship or her mentoring outcome variable (i.e., confidence in own STEM abilities or STEM-related activities) according to the mentees' "preferences." These preferences are expressed via log-odd ratios of different effects, similar to log-odds of logistic regression (Ripley et al., 2018). For example, if (in the simulation process) mentees tend to establish contact with other mentees who have a similar age to their own, this is expressed in the "similarity in age preference" by a *positive* log-odds value. If, on the other hand, (in the simulation process) mentees tend to establish peer relationships with both younger and older – but not similarly aged – mentees, then the corresponding "similarity in age preference" has a *negative* log-odds value.

Please note: during the simulation process, the mentees (i.e., the actors in the simulation) develop the structure of their peer relationship network; the network also influences the mentoring outcomes of the mentees (e.g., through peer influence). This suggests a causal association. However, as Ripley et al. (2018) wrote, "it does not necessarily reflect a commitment to or belief in any particular theory of action elaborated in the scientific disciplines" (p. 10). In addition, they note that although indications of causal effects may be inferred (as in comparable longitudinal study designs), these must be confirmed by further analyses. This means that the partly causal language used in our result and discussion sections explicitly refers to the simulation process and therefore must not be misinterpreted as actual decisions or beliefs of the mentees! For more information, refer to Snijders et al. (2010).

The model construction in RSiena is based on two categories of effects: effects that determine the development of the network (e.g., similarity in age) and effects that determine the development of attributes (e.g., peer influence regarding confidence in own STEM abilities and STEM-related activities) during the simulation process. A description of all effects that directly determine the development of the mentoring outcomes can be found in **Table 1**, these include the effects that test our hypotheses, covariates, and network model-specific effects. Moreover, a description of all other effects that solely determine the development of the peer relationship network can be found in the **Supplementary Table A1**.

The Online Mentoring Program CyberMentor as a Study Setting

We investigated our hypotheses with data from the online mentoring program, CyberMentor. CyberMentor is the biggest research-based, online mentoring program in STEM in Germany. It aims to increase the participation rate of female students in STEM. Participants are female students from university preparatory secondary schools throughout Germany, aged 12–18 years. Each girl receives guidance from a personal mentor who has a university degree in STEM. The communication with the mentor as well as with the other mentees and mentors who participate in the program (up to 800 per year) takes place on a secure online platform via internal email, chat and forum systems. Every participant has the possibility to communicate with every other participant. Moreover, each mentoring dyad is linked to another dyad on the platform. This group of four (constituted by two mentees and two mentors) is called a mentoring group. Each mentoring group shares a "virtual room" that contains profile pictures and descriptions of the four participants and gives them direct access to email and private chat messages within the mentoring group. Moreover, each mentoring group has access to a private forum and can initiate a group chat. These measures are intended to increase the communication between the members of the group of four participants. As mentioned above, the general forum, chat and email system also enables communication with other participants outside one's own mentoring group.

TABLE 1 | Short description of included effects for the simulation of mentoring outcomes in our RSiena models.

Effects	Short description
Hypotheses related effects	
Peer influence (Average similarity) (H1)	Test for *Hypothesis 1*. Is there peer influence on the mentoring outcomes? The average similarity effect expresses the preference of a mentee to become similar concerning the mentoring outcomes (i.e., concerning confidence in own STEM abilities and STEM-related activities) to the average value of her peers. If it is positive, then mentees tend to get more similar to their peer group, indicating peer influence, if negative, then mentees tend to get dissimilar to their peer group.
Moderation of mentee's age on peer influence (Average similarity × ego's age) (H2)	Test for *Hypothesis 2*. Is there a moderation of mentee's age on peer influence on mentoring outcomes? The age is centered by RSiena, hence the effect are to be interpreted as follows: A negative value would mean that younger mentees (i.e., beneath the mean age) get more similar to their peers than older mentees (i.e., above the mean age). A positive value would indicate the opposite.
Peer group size (Indegree) (H3)	Test for *Hypothesis 3*. Does the peer group size contribute to the peer influence on the mentoring outcomes? The peer group size counts the number of mentees an individual mentee has peer relationships with (i.e., indegree centrality). When it is positive, then it means the bigger the peer group size is, the more likely the mentees mentoring outcomes are influenced positively by the peer group.
Moderation of mentee's age on influence of peer group size (Age × Indegree) (H4)	Test for *Hypothesis 4*. Is the influence of the peer group size to the mentoring outcomes moderated by the mentee's age? The age is centered by RSiena, hence the effect to interpret as follow: A negative value would mean that for each additional peer mentee a younger mentee (i.e., beneath the mean age) is more likely to increase her own mentoring outcome level and an older mentee (i.e., above the mean age) is more likely to decrease her own mentoring outcome level. A positive value would mean the opposite.
Mentoring outcome related effects	
Linear shape	The linear shape effect expresses the basic drive toward high values on the mentoring outcome. A positive value indicates an increase, and a negative value a decrease.
Quadratic shape	The quadratic shape effect is the interaction of the mentoring outcome on itself over time: if it is positive, then it means there is positive feedback, thus the mentoring outcome tends to self-reinforce. In other words: mentees with a high mentoring outcome value at T1 tend to get even higher values at T2 and mentees with a low value at T1 tend to get even lower values at T2. If it is negative, then it can be regarded as negative feedback or a self-correcting mechanism. A mentee with a high value at T1, tend to decrease to T2, and mentees with low values, tend to increase, respectively.
Experience	Experience indicates whether a mentee has already participated in the mentoring program before and controls for that
Age	The age of the mentee was included as a control variable, in order to estimate the interaction of age with peer influence correctly.
Mentor relationships	The number of mentors, a mentee exchanges emails and private chat messages with (operationalized with the same cut-offs used to determine peer relationships) might be a confounding factor of peer influence.

Procedure and Sample

Our data collection took place on the online mentoring program CyberMentor. We collected two types of directed data to construct the peer relationship network: emails and private chat messages that participants wrote to each other. We did not include undirected data (i.e., from forums and group chats) in the network construction, as it is not possible to clearly identify who is addressing whom. During the data collection, a total of 430 mentees were registered in CyberMentor. All mentees (all female, M_{age} = 14.3 years, SD_{age} = 2.1, age range: 11–19, with one outlier of 8 years) were enrolled in high achiever-track secondary education in Germany. Their places of residence were scattered all over Germany, which means that mentees did not know each other at the beginning of their mentoring (in any case, the probability of this happening is negligible).

In order to model the peer networks correctly, we only included "active" mentees (N = 124; 28.8%) in our sample. We defined "active" mentees as mentees that had at least one peer relationship during mentoring (i.e., at least four written emails or 15 written private chat messages; for more information refer to section "Derived Variables From Log Files")[1]. To address possible influence of mentors, we also included the number of mentors that a mentee repeatedly wrote emails or private chat messages to during 6 months of mentoring. Here we define a mentor relationship by the same cut-off value as a peer relationship (i.e., at least four written emails or 15 written private chat messages; for more information refer to section "Derived Variables From Log Files"). After 1 year of mentoring, mentees (and mentors) are given the opportunity to participate again. The re-enrolled (referred to as "experienced") mentees can choose if they want to stay with their former mentor or be assigned to a new mentor. Of the 124 mentees, 100 (80.6%) were first-time participants, and 24 (19.4%) were experienced mentees (i.e., had already participated in CyberMentor at least once before as a mentee).

Measures

Data Collection Process

Online questionnaires

All mentees were asked to complete an online questionnaire about confidence in their own STEM abilities and their STEM-related activities before the mentoring year (T1) and after 6 months of mentoring (T2).

[1] At the beginning of mentoring, active mentees did not differ significantly in their age or in regard to the two mentoring outcomes. However, after 6 months of mentoring, slightly better mentoring outcomes were found for the mentees with at least one peer relationship. A more detailed comparison of the included and excluded mentees can be found at the beginning of the results section. In the following, we will only refer to the sample consisting of 124 active mentees.

Log files

Between T1 and T2, program participants' platform communication was retained via anonymized log files. The data was collected in the following way. An automated script extracted the following attributes of all email and private chat message log files: sender-ID, receiver-ID, and timecode written.

Further data

Additional to the questionnaire and log file data, we extracted the mentee's age at the beginning of the mentoring year, their mentoring group affiliation, and whether they had participated in the program the previous year.

Derived Variables From Questionnaires

Confidence in own STEM abilities

We assessed students' confidence in their own STEM abilities using a domain-specific version of the scale "Belief in one's own abilities." (Dweck, 1999). This four-item scale measures how confident students are in their (in this case STEM-related) abilities. Two endpoints are formulated as statements, e.g., "I do not have a great deal of confidence in my STEM abilities" vs. "I am confident in my STEM abilities." Each of the statements in an item pair represents one pole on a six-point scale. A low value represents little confidence in one's own STEM abilities. Confidence in one's own STEM abilities was measured both at the beginning of the mentoring (T1) and 6 months later (T2). The scale showed a good one-dimensionality, indicated by McDonald's $\omega_{h,T1} = 0.83$ and $\omega_{h,T2} = 0.78$ which gives the proportion of variance in scale scores accounted for by a general factor (McDonald, 1999). High ω total values of McDonald's $\omega_{t,T1} = 0.88$ and $\omega_{t,T2} = 0.88$, respectively indicated a reliable multidimensional composite (Watkins, 2017). The scale showed good internal consistency of Cronbach's $\alpha_{T1} = 0.85$ and $\alpha_{T2} = 0.83$, respectively.

STEM-related activities

We used a 9-item scale for assessing mentees' STEM-related activities (Stoeger et al., 2013). Respondents indicated on a 6-point Likert-type scale (with "1" = strongly disagree and "6" = strongly agree) to what extent they partake in STEM-related activities, e.g., reading STEM-related books or attending STEM-related extracurricular lectures. Sample item: "I very often read articles about STEM topics." STEM-related activities were measured both at the beginning of mentoring (T1) and 6 months later (T2). The scale showed an acceptable one-dimensionality, indicated by McDonald's $\omega_{h,T1} = 0.58$ and $\omega_{h,T2} = 0.59$ which gives the proportion of variance in scale scores accounted for by a general factor (McDonald, 1999). High ω total values of McDonald's $\omega_{t,T1} = 0.85$ and $\omega_{t,T2} = 0.84$, respectively indicated a reliable multidimensional composite (Watkins, 2017). The scale showed good internal consistency of Cronbach's $\alpha_{T1} = 0.81$ and $\alpha_{T2} = 0.78$, respectively.

Conversion of questionnaire data

As the method RSiena used for our network analyses needs whole number (integer) values of data, we converted the 1–6 valued decimal number format scales of the two variables with the range of 5 by multiplying all values by 2 and rounding the results to integers, resulting in a 2–12 valued integer number format scale with the range of 10.

Derived Variables From Log Files

Peer relationship networks

Every mentee of our sample can theoretically have up to 123 peer relationships (with other mentees). These peer relationships are coded in so-called adjacency matrices. In our case, such an adjacency matrix is 124 × 124 in size, i.e., it consists of 15,376 elements. Each line of the matrix codes the relationships of one mentee, whereby the value "1" stands for a peer relationship and the value "0" for no peer relationship. Please note that the method we use does not support weighted relationships, i.e., values higher than "1"). For our longitudinal network analyses, we created two adjacency matrices. One maps all peer relationships for the first 4 weeks, the other maps all peer relationships for the following 5 months of mentoring (see section "Plan of Analysis" for more details). These peer relationships are (in our case) directed. This means a mentee A can have a peer relationship to mentee B, but mentee B does not need to have a peer relationship to mentee A (i.e., reciprocal peer relationships are not required).

To derive the peer relationship networks of the sampled mentees on the online mentoring platform CyberMentor, a proper measure must be set to distinguish when a "real" peer relationship between relevant participants can and cannot be assumed. For a peer relationship between two mentees to be considered as such, repeated communication has to be observed (Roberts and Dunbar, 2011), especially if the communication takes place exclusively on an online platform (Arnaboldi et al., 2013). Previous research suggested several different methods to distinguish strong from weak relationships (Schaefer et al., 2010; Daniel et al., 2013). The underlying assumption of these methods is that all participants in the network know each other. However, this does not apply to the online mentoring context at hand. Thus, we defined an existing (directed) relationship ("1") from mentee A to another mentee B for a given time (after 4 weeks or 6 months of mentoring), when the number of written messages from mentee A to mentee B laid in the upper quartile of all mentee-to-mentee written messages, i.e., at least four written emails or at least 15 written private chat messages. For example, if mentee A wrote mentee B four emails and seven private chat messages and mentee A wrote mentee C one email and 20 private chat messages in the first 4 weeks, then mentee A had a peer relationship to mentee B as well as to mentee C in the first adjacency matrix (T1).

Peer group size

The peer group size is the number of mentees that a specific mentee has peer relationships with. This is identical to the indegree centrality of the directed peer relationship network (Wassermann and Faust, 1994). For example, if mentee A has only peer relationships with mentees B and C, then the peer group size of mentee A is two. For each mentee, two values were derived from the adjacency matrices of peer relationships, indicating the number of peer relationships a mentee had

during the first 4 weeks of mentoring and during the remaining time of mentoring.

Covariates

We also included several control variables that are important for our later analysis.

Age

The age (in years) of a mentee at the beginning of mentoring.

Mentoring group membership

As mentioned in section "The Online Mentoring Program CyberMentor as a Study Setting," mentoring dyads share a "virtual room" with another mentoring dyad on the platform. We call this group of four individuals (or two mentoring dyads) mentoring group. Although every mentee theoretically can communicate with every other mentee or mentor in the program, this might not be the case in actuality. Through the design of the CyberMentor website, the mentee might be more aware of a partner mentee (and the mentor of the other dyad) in the mentoring group, theoretically increasing the probability of an exchange between two mentees of the same mentoring group. For this reason, we included mentoring group membership as a covariate.

Mentoring experience

After 1 year of mentoring, the mentees are offered the opportunity to participate in mentoring program for another year. Thus, our sample contained both mentees without previous mentoring experience (i.e., inexperienced, coded as "0") and mentees with mentoring experience (i.e., experienced, coded as "1"). As mentees' experience might have an influence on their mentoring outcomes, we controlled for mentoring experience in our analyses.

Mentor relationships

The number of mentors with which a mentee exchanges email and private chat messages during mentoring might affect the mentee's mentoring outcome. We included the number of mentors a mentee had contact with during mentoring by using the same threshold of written emails and private chat messages for determining peer relationships (i.e., 4 written emails or 15 written private chat messages).

Plan of Analysis

All statistical analyses were conducted within the R software environment for statistical computing and graphics (R Core Team, 2017) and the R package psych v1.8.12 (Revelle, 2018) unless otherwise stated. We mainly carried out four steps:

1. Treatment of missing values in our two variables of interest (i.e., confidence in own STEM abilities and STEM-related activities),
2. Pre-analysis, how the participants that we excluded from the analyses (mentees without at least one peer) differ from participants that were included in the analysis (mentees with at least one peer),
3. Descriptives regarding mentoring outcomes and the peer relationship network,
4. Longitudinal network analyses to test our four hypotheses concerning the development of mentees' confidence in their own STEM abilities and their STEM-related activities.

For our longitudinal network analyses, we set our alpha level to 0.1. With an increased alpha of 0.1 instead of the conventional 0.05 the false negative rate is decreased (Miller and Ulrich, 2019). By conducting (to our knowledge) the first study examining peer influences in online mentoring, it was important for us to minimize false negative outcomes and thereby open up more room for potential future research (as suggested by Fiedler et al., 2012). For our other analyses (i.e., step 1–3), we used the (for social sciences) conventional alpha level of 0.05.

Missing Data

For imputing missing data, we utilized the R package MICE v2.30 and used the implemented predictive mean matching method for multiple imputation (van Buuren and Groothuis-Oudshoorn, 2011). We adjusted the number of imputations according to recommendations for the current missing pattern, i.e., 40 imputed datasets for 50% missing values, as recommended by Graham et al. (2007). We observed sufficient convergence of the algorithm (using 40 iterations).

The current version of the package for longitudinal network analysis, RSiena v1.2-4 (Ripley et al., 2018) cannot handle multiple imputed data (regarding the mentoring outcome variables, i.e., confidence in own STEM abilities and STEM-related activities). Thus, we combined the imputed data sets by calculating the mean of each 40 imputed values for each cell of the final data frame.

Pre-analysis: Differences Between Mentees With at Least One Peer Relationship and Mentees Without Any Peer Relationships

In our pre-analysis, we wanted to show, that the included mentees were fairly similar to the group of excluded mentees at the start of the mentoring. Moreover, if a difference between the two groups is detected after 6 months of mentoring, this would already be a (weak) indication that the exchange with peers can have an impact on the mentoring success of mentees. Thus, we compared the two groups with independent *t*-tests and the false discovery rate (FDR) correction for multiple comparisons (Benjamini and Hochberg, 1995) regarding their age, confidence in their own STEM abilities (T1 and T2), and their STEM-related activities (T1 and T2).

Descriptives

We derived descriptives of the mentoring outcomes (i.e., confidence in own STEM abilities and STEM-related activities) and peer relationships as well as network related measures, i.e., total number of existing relationships between mentees, the average degree centrality, density, and reciprocity. The average degree centrality corresponds to the average number of peers a mentee has during online mentoring. "Density" refers to the proportion of observed peer relationships (edges) relative to the – hypothetically – total number of possible peer relationships (edges); possible values can range between zero and one. The reciprocity in the peer relationship network represents the

amount of peer relationships (edges) in the network that are reciprocal; possible values can range between zero and one.

Longitudinal Network Analysis

The main longitudinal social network analysis was done with the R package RSiena v1.2-4 (Ripley et al., 2018). The aim of the analysis is to explain the change of confidence in mentees' own STEM abilities and their STEM-related activities during 6 months of mentoring. In this method, all four hypotheses are considered simultaneously (and thus, a possible confounding between them can be considered).

In **Table 1** and **Supplementary Table A1**, all relevant parameters used in the model are described in detail. **Table 1** describes the effects that are used to answer the research questions (i.e., the effects that determine the development of the mentoring outcomes, including possible confounding covariates). The simultaneous development of the associated peer relationship networks (including the control of selection effects) are described in **Supplementary Table A2**. In the following – for easier understanding of the results – the effect names used to test our hypotheses are listed: *Hypothesis 1:* Peer influence (Average similarity), *Hypothesis 2:* Moderation of mentee's age on peer influence (Average similarity × ego's age), *Hypothesis 3:* Influence of a mentee's peer group size (Indegree), *Hypothesis 4:* Moderation of mentee's age on influence of peer group size (Age × peer group size).

Note that all variables are centered internally by RSiena. This means that the values of interaction effects with age (i.e., hypothesis 2 and hypothesis 4) must be interpreted in the following way. A positive value of the moderation effect in hypothesis 2 would mean: mentees below average age become more dissimilar to their peers and mentees above average age become more similar to their peers (with regard to the mentoring outcome considered). A negative effect would mean that mentees below average age would become more similar to their peers and mentees above average age would become less similar. A more detailed explanation on how to interpret all effects, can be found in **Table 1** and **Supplementary Table A1**.

As RSiena can be tweaked in many ways, after several test runs, we decided to increase the iteration steps from the initial four up to five, to increase the precision of the algorithm. To increase the estimation precision of the standard error (and thus the precision of the *p*-value), we increased the steps of the third phase of the RSiena estimation process to 4000 as recommended (Ripley et al., 2018). The participants' mentoring outcome variables were negatively skewed; therefore, we decided to use the boundary-absorbing behavior model. As Ripley et al. (2018) state, it shows better fit, by allowing changing the mentoring outcome variable one step further even though the current state is already in its maximum value.

RESULTS

Missing Data

An inspection of the data revealed that the missing values followed a missing at random pattern. In the online questionnaire dataset, there was a mean rate of 22% missing values at the first measurement point T1 and a mean rate of 50% missing values at the second measurement point T2. In order to impute missing values based on maximum information, we utilized multiple imputations with the complete (N = 430 cases) questionnaire data set (Newman, 2014). All subsequent analyses were then performed on the data obtained.

Pre-analysis: Comparison Between Mentees With at Least One Peer Relationship and Mentees Without Any Peer Relationship

We compared the group of mentees that we included into our further analyses (mentees with at least one peer relationship; N = 124) with the group of mentees that we excluded from the analyses (mentees without a peer relationship; N = 306) with help of an independent *t*-tests, using FDR correction for multiple comparisons (Benjamini and Hochberg, 1995), regarding their age, confidence in their own STEM abilities, and their STEM-related activities. The results are shown in **Table 2**. At the beginning of mentoring (T1), the two groups did not differ significantly in age or regarding the two dependent variables: confidence in own STEM abilities and STEM-related activities.

After 6 months of mentoring (T2), significant differences between the two groups indicate that mentees that interacted more intensely with other mentees on the platform had higher values in STEM-related activities than mentees that stayed relatively isolated from other mentees ($t(428) = 2.96$, $p_{FDR} = 0.01$, Cohen's d = 0.31). Mentees with peer relationships showed similar confidence in their own STEM abilities after 6 months of mentoring at T2 compared to mentees without peer relationships ($t(428) = 2.31$, $p_{FDR} = 0.05$, Cohen's $d = 0.25$).

Descriptives

Mentoring Outcomes

The descriptives of the two mentoring outcomes: confidence in own STEM abilities and STEM-related activities, and the number of peer relationships of the mentees can be found in **Table 2**. Mentees did not differ significantly between T1 and T2 regarding their means in confidence in own STEM abilities (paired *t*-test, $t(123) = -0.02$, $p_{FDR} = 0.98$, Cohen's $|d| < 0.01$) or STEM-related activities ($t(123) = 2.26$, $p_{FDR} = 0.05$, Cohen's $d = 0.22$).

Peer Relationship Networks

The descriptive statistics of the two waves of the peer relationship network at the beginning (4 weeks) of the mentoring and the remaining 5 months of mentoring are shown in **Table 3**. Overall, the peer relationship network became denser throughout mentoring. The reciprocity remained unchanged, i.e., 83% of all peer relationships were reciprocal.

Results of Longitudinal Network Analyses

Model Convergences and Quality

To anticipate possible convergence problems, we examined the so-called Jaccard index. This is the amount of unchanged

TABLE 2 | Results of the *t*-tests between mentees and without a peer relationship (wop) with at least one peer relationship (wp).

Variable	M_{wop} (SD)	M_{wp} (SD)	*t*(428)	*p*	p_{FDR}	*d*
Age	14.31 (2.09)	14.31 (2.17)	0.02	0.99	0.99	0.00
Confidence in own STEM abilities T1	4.38 (0.97)	4.58 (0.91)	1.92	0.06	0.09	0.20
Confidence in own STEM abilities T2	4.38 (0.81)	4.57 (0.76)	2.31	0.02	0.05	0.25
STEM-related activities T1	3.72 (0.90)	3.89 (0.86)	1.77	0.08	0.10	0.19
STEM-related activities T2	3.85 (0.66)	4.06 (0.69)	2.96	< 0.01	**0.02**	0.31
Number of peer relationships T1	0 (0)	1.15 (1.75)	–	–	–	–
Number of peer relationships T2	0 (0)	1.58 (2.81)	–	–	–	–

p_{FDR} is the false positive rate corrected significance level; d is Cohen's d. $p_{corr} < 0.05$ is marked bold.

TABLE 3 | Descriptive statistics of the used networks.

Network	Number of nodes	Number of edges	Average degree	Density	Reciprocity
Wave T1	124	143	1.15	0.009	0.83
Wave T2	124	196	1.58	0.013	0.83

edges between T1 and T2 of the peer relationship networks, and the calculated value of 0.37 is considered good (Ripley et al., 2018).

For assessing convergence of the following analyses, the indices "convergence t ratios" and "overall maximum convergence ratio" are suitable. Indications of good convergence are convergence t ratios smaller than 0.1 and maximum convergence t ratios smaller than 0.25 (Ripley et al., 2018). In all calculated models, the corresponding indices were satisfactory (refer to **Table 4** for exact values).

Moreover, we considered three indicators for model fit: the indegree distributions, the out-degree distributions, and the mentoring outcomes distributions. The corresponding Monte Carlo Mahalanobis distance tests were calculated, where a good fit is indicated by a non-significant *p*-value. Each value (in-degree, out-degree, and mentoring outcomes distributions) was in the non-significant range ($p > 0.05$), thus indicating an acceptable fit of the models.

RSiena Model Results

All results of the RSiena model regarding the research questions can be found in **Table 4** and will be described in more detail. To help interpret the results, it is important to know the average number of "decision opportunities" a mentee is given in the RSiena simulation. As noted in **Supplementary Table A2**, in our RSiena simulations regarding confidence in own STEM abilities, each mentee is given on average 5.55 (SD = 1.67) "decision opportunities" to change her confidence in STEM abilities by a value of 0.5. Regarding STEM-related activities, each mentee is given on average 5.33 (SD = 1.09) "decision opportunities" to change her STEM-related activities by a value of 0.5. This means that a mentee can (on average) increase or decrease her mentoring outcome by a maximum value of $5 \times 0.5 = 2.5$ (if, at each "decision opportunity" in the simulation, she prefers the same change in her mentoring outcome).

Hypothesis 1: Mentees are subject to peer influence in online mentoring, regarding (H1a) confidence in own STEM abilities and (H1b) STEM-related activities

Confidence in own STEM abilities. We did not find evidence indicating unmoderated peer influence on confidence in own STEM abilities ($\beta = -5.13$, SE = 4.07, two-sided $p = 0.21$, **Table 4**). Therefore, we reject Hypothesis H1a.

STEM-related activities. We did not find evidence indicating unmoderated peer influence on STEM-related activities ($\beta = 2.53$, SE = 2.58, two-sided $p = 0.32$, **Table 4**). Therefore, we reject Hypothesis H1b.

Hypothesis 2: The mentee's age moderates the peer influence that a mentee is subject to in the following way: younger mentees are more susceptible to peer influence (than older mentees) in both (H2a) their confidence in STEM abilities and (H2b) their STEM-related activities

Confidence in own STEM abilities. We found significant evidence for the hypothesized moderating effect of age on peer influence on confidence in own STEM abilities ($\beta = -1.52$, SE = 1.10, one-sided $p = 0.08$). The negative value of the effect (**Table 4**) indicates that younger mentees (below the average age) have a positive similarity effect, i.e., they tend to grow more similar to the mentees they have a peer relationship with regarding confidence in own STEM abilities. More precisely: If a 11.2 years old mentee (*mean* age – 1.5 SD) has peer relationships to mentees with *higher* confidence in their own STEM abilities than herself, then the mentee has a 65% higher chance of *increasing* her confidence in her own STEM abilities (by a value of 0.5, in the event of a "decision opportunity") than without these mentees (given all other parameters are constant). In other words: if we compare two identical 11.2-year-old mentees, mentee A and mentee B, where mentee A has peers (with a *higher* confidence in their own STEM abilities) but mentee B has none, then in the event of a "decision opportunity," the probability for mentee A to *increase* her confidence in own STEM abilities (by a value of 0.5) is 1.65 times higher than it is for mentee B. Analogously, mentee A is 1.65 times more likely to *decrease* confidence in her own STEM abilities if her peers have *lower* confidence in their own STEM abilities.

This susceptibility to peer influence decreases with increasing age. In the case of older mentees (above the average), this effect reverses, i.e., their STEM confidence is increasingly moving

TABLE 4 | RSiena model results of both mentoring outcomes.

	Confidence in own STEM abilities				STEM-related activities			
Effects	**Effect value**	**SE**	***t* stat**	***p***	**Effect value**	**SE**	***t* stat**	***p***
Hypotheses related effects								
Peer influence (Average similarity) (H1)	−5.13	4.07	−1.26	0.21	2.53	2.58	0.98	0.16
Moderation of mentee's age on peer influence (Average similarity × ego's age) (H2)	−1.52	1.10	−1.38	**0.08**	−1.44	0.97	−1.49	**0.07**
Peer group size (Indegree) (H3)	0.23	0.22	1.04	0.15	0.05	0.09	0.54	0.30
Moderation of mentee's age on influence of peer group size (Age × Indegree) (H4)	−0.21	0.15	−1.39	**0.08**	0.01	0.04	0.17	0.43
Mentoring outcome related effects								
Linear shape	−0.26	0.24	−1.10	0.27	0.05	0.14	0.37	0.71
Quadratic shape	−0.29	0.13	−2.26	**0.02**	−0.16	0.05	−3.34	**< 0.01**
Experience	0.29	0.26	1.13	0.26	0.68	0.21	3.20	**< 0.01**
Age	0.16	0.14	1.12	0.26	−0.06	0.07	−0.86	0.39
Mentor relationships	0.11	0.11	1.07	0.28	0.07	0.05	1.33	0.20

All convergence t ratios < 0.07, overall maximum convergence ratios < 0.13; p-values smaller than 0.1 are marked bold; each p-value is for two-sided tests, except the p-values of "moderation of mentee's age on peer influence," "peer group size," and "moderation of mentee's age on influence of peer group size."

away from the mentees they have a peer relationship with. More precisely: If a 17.5 years old mentee (*mean* age + 1.5 SD) has peer relationships to mentees with *higher* confidence in STEM abilities than herself, then the mentee has a 65% higher chance of *decreasing* her confidence in STEM abilities (by a value of 0.5, in the event of a "decision opportunity") than without these mentees (given all other parameters are constant). In other words: if we again compare two identical 17.5-year-old mentees, mentee C and mentee D, where mentee C has peers (with a *higher* confidence in their own STEM abilities) but mentee D has no peers, in the event of a "decision opportunity," the probability for mentee C to *decrease* confidence in her own STEM abilities (by a value of 0.5) is 1.65 times higher than it is for mentee D. Analogously, mentee C is 1.65 times more likely to *increase* confidence in her STEM abilities if her peers have *lower* confidence in their own STEM abilities.

Overall, the younger a mentee is, the more likely she adapts the level of her own confidence in STEM abilities to the level of her peers' confidence in their own abilities. Thus, we accept Hypothesis H2a.

STEM-related activities. We found marginally significant evidence indicating the hypothesized moderating effect of age on peer influence on STEM-related activities ($\beta = -1.44$, SE = 0.97, one-sided $p = 0.07$). The negative value of the corresponding effect (**Table 4**) indicates, that younger mentees (below the average age) have a positive similarity effect, i.e., they tend to become more similar to the mentees they have a peer relationship in regards to STEM-related activities. More precisely: If a 11.2 years old mentee (*mean* age – 1.5 SD) has peer relationships with mentees with *higher* STEM-related activities than herself, then the mentee has a 61% higher chance to *increase* her STEM-related activities (by a value of 0.5, in the event of a "decision opportunity") than without these mentees (given all other parameters are constant). In other words: if we compare two identical 11.2-year-old mentees, mentee A and mentee B, where mentee A has peers (with a *higher* level of STEM-related activities) but mentee B has none, then in the event of a "decision opportunity," the probability for mentee A to *increase* her STEM-related activities (by a value of 0.5) is 1.61 times higher than it is for mentee B. Analogously, mentee A is 1.61 times more likely to *decrease* her STEM-related activities if her peers have *lower* STEM-related activities.

This susceptibility to peer influence decreases with increasing age. In the case of older mentees (above the average), the effect reverses, i.e., their level of STEM-related activities is increasingly moving away from the mentees they have a peer relationship with. More precisely: If a 17.5 years old mentee (*mean* age + 1.5 SD) has peer relationships to mentees with *higher* STEM-related activities than herself, then the mentee has a 61% higher chance to *decrease* her STEM-related activities (by a value of 0.5, in the event of a "decision opportunity") than without these mentees (given all other parameters are constant). In other words: if we again compare two identical 17.5-year-old mentees, mentee C and mentee D, where mentee C has peers (with a *higher* degree of STEM-related activities) but mentee D has none, then in the event of a "decision opportunity," the probability for mentee C to *decrease* her STEM-related activities (by a value of 0.5) is 1.61 times higher than it is for mentee D. Analogously, mentee C is 1.61 times more likely to *increase* her STEM-related activities if her peers have *lower* STEM-related activities.

Overall, the younger a mentee is, the more likely she adapts her own level of STEM-related activities to the level of her peers' STEM-related activities. Thus, we accept Hypothesis H2b.

Hypothesis 3: The size of the peer group (operationalized by the number of peers that regularly send messages to the mentee) contributes positively to the mentoring outcomes in the following way: The larger the size of the peer group a mentee interacts with the more positive the development of her (H3a) confidence in own STEM abilities and (H3b) STEM-related activities

Confidence in own STEM abilities. We found no evidence that the size of a mentee's peer group positively contributes to mentees' confidence in own STEM abilities (β = 0.23, SE = 0.22, one-sided $p = 0.15$, **Table 4**. Thus, we reject hypothesis H3a.

STEM-related activities. We found no evidence that the size of a mentee's peer group positively contributes to STEM-related activities (β = 0.05, SE = 0.09, one-sided $p = 0.30$, **Table 4**). Thus, we reject hypothesis H3b.

Hypothesis 4: The influence of the size of the peer group (operationalized by the number of peers that regularly send messages to the mentee) on the mentoring outcomes is moderated by the mentee's age in the following way: The older mentees are, the less they benefit from an increasing size of their peer group regarding (H4a) their confidence in STEM abilities and (H4b) their STEM-related activities

Confidence in own STEM abilities. We found significant evidence of a moderation of age on the influence of the size of the peer group on the confidence in own STEM ability (β = −0.21, SE = 0.15, one-sided $p = 0.08$). The expected negative value of the effect (**Table 4**) indicates, that for younger mentees (below the average age) each additional peer relationship increases the likelihood that the mentee improves her confidence in own STEM abilities, exponentially (i.e., $\exp[(-1.5 \times SD_{age}) \times (-0.21) \times n]$, where n stands for the number of peers, SD_{age} for the standard deviation of mentees' age, and exp for the exponential function). More precisely, one additional peer relationship of an 11.2 years old mentee (*mean* age – 1.5 SD) increases the mentee's likelihood by 100% of increasing her level of confidence in own STEM abilities (by a value of 0.5, in the event of a "decision opportunity"; given all other parameters are constant). Four additional peer relationships of an 11.2 years old mentee increase the aforementioned likelihood by 1499% (i.e., nearly 15 times). In other words: if we compare two identical 11.2-year-old mentees, mentee A and mentee B, where mentee A has four peers but mentee B has zero peers, then in the event of a "decision opportunity," the probability for mentee A to *increase* her confidence in own STEM abilities (by a value of 0.5) is 15.99 times higher than for mentee B.

The observed moderation of mentee's age indicates, that for the average old mentees, there is no peer group effect. Moreover, in older mentees, one additional peer relationship of a 17.5 years old mentee (*mean* age + 1.5 SD) increases the likelihood by 100% of a *decrease* in her level of confidence in own STEM abilities (analogous to young mentees, by a value of 0.5, in the event of a "decision opportunity"; given all other parameters are constant). Thus, we accept hypothesis H4a.

STEM-related activities. We found no evidence that the contribution of a mentee's peer group to STEM-related activities is moderated by age (β = 0.01, SE = 0.04, one-sided $p = 0.43$, **Table 4**). Thus, we reject hypothesis H4b.

DISCUSSION

The main objective of our study was to investigate peer influence in online mentoring. We analyzed whether mentoring outcomes – namely confidence in own STEM abilities and STEM-related activities – are influenced by networking with other mentees on the mentoring platform. As research shows that peer influence differs during development (e.g., Steinberg and Monahan, 2007), we also investigated the moderating role of age for peer influence on mentoring outcomes. Furthermore, we investigated the role of peer group size concerning peer influence on mentoring outcomes (as indicated by e.g., Wang et al., 2016). To obtain more reliable estimates of peer influence effects, we controlled for selection processes that determine the peer relationship network evolution, for mentoring experience, as well as for the number of mentors in a mentee's email and private chat message exchange. As our method, we conducted a longitudinal social network analysis, using an stochastic actor based simulation approach (Snijders et al., 2010; i.e., RSiena; Ripley et al., 2018).

Overall, our findings suggest peer influence for both our examined mentoring outcomes, i.e., confidence in own STEM abilities and STEM-related activities in STEM. However, while we did not find an age-independent peer influence on mentoring outcomes, we found an age-moderated effect. Younger mentees tend to adapt to their peers' average level of mentoring outcomes, whereas older mentees tend to distance themselves from the average mentoring outcome level of their peers.

This finding is consistent with research from offline contexts (Steinberg and Monahan, 2007; Aral and Walker, 2012) and online contexts outside the field of mentoring (Aral and Walker, 2012; Bapna and Umyarov, 2015). Some researchers would call this pattern of results increasing resistance against peer influence (Steinberg and Monahan, 2007). Our results indicate that resistance against peer influence in our sample seems to manifest itself in the following way: older mentees (i.e., girls above the mean age of 14.3 years) become more dissimilar to their peers, both in their confidence in own STEM abilities and their STEM-related activities.

The observed results might be attributable to the way peer relationships between mentees are formed. For example, our peer network development statistics (see **Supplementary Table A2**) show that relationships between young, inexperienced mentees and older, more experienced mentees are more likely to develop. Thus, younger mentees might have a type of unofficial "peer-mentor" that is more similar to them than their official mentor (Colvin and Ashman, 2010), and by whom they are more strongly influenced (Karcher, 2013). The same mechanism does not ring true for older mentees. In future studies this assumption – and especially potentially existing informal peer mentoring relationships in online mentoring – should be considered, preferably with a bigger sample. For example, in future studies, mentees could be explicitly asked

if and with which of their peers a form of mentoring relationship exists.

Another age-dependent finding of our study was that the size of the peer group positively impacts confidence in own STEM abilities – but not STEM-related activities. The effect of peer group size on mentoring outcomes is higher in young mentees than in older mentees. More precisely: the larger the peer group of a young mentee is, the more likely she is to increase her confidence in own STEM abilities during mentoring. One reason for the supporting role of the size of the online peer group for young mentees might be that in comparison to other settings (e.g., school), during online mentoring mentees have the chance to communicate with other like-minded peers. This might lead mentees to re-evaluate themselves positively due to their newly enriched social environment (Berndt and Ladd, 1989), thus increasing their confidence in own STEM abilities. Moreover, a larger peer network seems to heighten the commitment to visit the online mentoring platform more often (Schimke et al., 2009), which in turn leads to positive mentoring outcomes (Stoeger et al., 2016). Older mentees (over 14.3 years of age), however, do not benefit from a large peer group size. The phenomenon of social comparison might explain our age moderated findings. Individuals tend to evaluate their own abilities, opinions, attitudes and other self-aspects in relation to other individuals (Guyer and Vaughan-Johnston, 2018). A comparison with status-higher individuals (upward comparison) often hinders self-aspects, whereas a comparison with status-lower individuals (downward comparison) tends to support self-aspects. Female students tend to have a tendency to compare upward (Pulford et al., 2018), an approach that increases with age (Martin and Kennedy, 2003), thus being in line with our observed results.

Surprisingly, we did not find any impact of the size of the peer group on STEM-related activities – neither age independent, nor age dependent. This finding might be put in perspective by a comparison with results of other studies on online mentoring (Hopp et al., 2014; Stoeger et al., 2016). First, it could be shown that STEM-related activities are influenced by STEM-related messages exchanged between mentees as well as between mentees and mentors (Stoeger et al., 2016). Here lie the main differences in our study since we only examined the messages between mentees and did not examine the message contents (STEM-related vs. non-STEM-related). Moreover, the impact of the peer group can be understood as a kind of contagion process (Dasgupta, 2011). Thus, it is important that the actual "virus" (i.e., embedded in STEM-related content) is exchanged in order to get infected. Earlier analyses showed that a network measure similar to the size of the peer group (i.e., Hopp et al., 2014) can have a positive influence on STEM-related activities of mentees, but only when the STEM content of communication within the network (i.e., STEM-related emails) was taken into account.

Furthermore, the mentors – and not the peers – of the mentees could be the main initiators of STEM-related activities. This assumption is supported by the implementation of mentoring in CyberMentor (i.e., the program under investigation). The program offers STEM-related project ideas (e.g., explaining everyday STEM-related phenomena or STEM experiment instructions) that are intended to strengthen the cooperation between mentor and mentee as well as the mentee's STEM related activities. Several studies show that the program has a positive influence on mentees' STEM activities (Stoeger et al., 2013, 2016). There is also evidence that mentors play an important role for increases in STEM activities (Stoeger et al., 2019). In future research, it would be interesting to investigate more thoroughly how peer- and mentor-influences interact when it comes to increasing STEM activities in the CyberMentor program.

Limitations

In our study, we found initial evidence of peer influence on mentoring outcomes. However, there were several limitations to our research that should be kept in mind when interpreting the results.

First, we must address a few issues regarding our sample. Our sample consists exclusively of girls, which seems to be adequate for mentoring in STEM as programs in this area try to reduce negative gender-related stereotypes toward the field – something more easily achieved by exclusively providing female role models (e.g., Stout et al., 2011). However, it is not clear whether our results can be generalized to peer influence in STEM mentoring programs with male and female mentees. In these programs, peer influence might be moderated by gender, as suggested by some research (e.g., Brechwald and Prinstein, 2011). Moreover, to acquire more robust results of the used longitudinal network analysis method, our sample is based on active mentees, i.e., mentees that wrote at least four emails to another mentee over the course of 6 months. Thus, the results may not be generalizable to all participating mentees of CyberMentor. Overall, future studies should include a more varied sample to address the mentioned sample limitations.

Second, we found relatively weak effects, or in some cases no effects at all. One reason might be that – as earlier studies showed (Stoeger et al., 2016) – mostly girls with a high STEM interest are attending CyberMentor. This might lead to a restriction of variances and thus, to smaller effects. Another reason for the small effects could be the missing focus on the content of communication. Further research should include various aspects of the content of communication (e.g., relation to STEM or emotional characteristics) in order to better understand peer influence and relationships between mentees. The quality of relationships between mentees, but also between mentees and mentors might moderate peer influence. For example, mentees with a need for improvement in their relationship with their mentor might be more receptive to peer influence. However, it might also be the case (as one reviewer suggested) that individuals with stronger relationships with their mentor might be more likely to reach out to more peers (for example, because individuals with stronger mentor relationships might develop the confidence to do so). In future studies, the relationship quality between mentee and mentor should be taken into account. Overall, future studies should investigate further moderation effects on peer influence and use bigger sample sizes.

Conclusion and Key Implications

Overall, and to the best of our knowledge, this is the first study that analyzed peer influence in online mentoring on mentoring outcomes for girls in STEM (i.e., confidence in own STEM abilities and STEM-related activities). Our study suggests that not only do mentors influence mentoring outcomes, peers (other mentees) with whom the girls communicate on the mentoring platform do, too. The age of the mentees seems to play an important role with younger mentees adapting to the mentoring outcome level of their peers over the course of mentoring, and with older mentees diverging from their peers over time. In addition, stronger networking with peers (i.e., the size of the peer group) on the platform increased confidence in own STEM abilities of the mentees in our study, but only for young mentees.

It is much too early to infer recommendations for practice from our results. Should future research support our findings there might be some suggestions for platform structuring and group composition in online mentoring for girls. Our results are initial evidence that the more peers a young mentee has, the better it might be for her confidence in own STEM abilities. Therefore, the development of peer relationships in online mentoring programs should be encouraged – especially for young mentees. To accomplish this, easily accessible communication possibilities can be offered on the online platforms. This might increase the probability that these means of communication will be used, which is also indicated by our results (see **Supplementary Table A2**): mentees communicate with peer mentees from their own mentoring group – with whom they share special communication tools – rather than with other mentees on the platform.

In addition, initial – albeit, highly speculative – we found indications for the set-up of mentoring groups. On the one hand, our results indicate that age is a moderator on peer group size (see **Supplementary Table A2**), i.e., older mentees are more likely to side with younger – and thus often inexperienced – mentees. On the other hand, we observed a moderation of the mentee's age on peer influences in both mentoring outcomes (i.e., confidence in own STEM abilities and STEM-related activities): young mentees show a tendency to adapt the mentoring outcome of their peers, whereas older mentees show an opposite behavior. Taken together, a mentoring group where a young mentee has the possibility to exchange with an older, more experienced mentee might be beneficial for both parties. However, the evidence that the current study provides is too weak to make strong inferences regarding platform structuring and group composition in online mentoring for girls.

Overall, our results provide initial evidence of the positive impact of peer influence and networking between mentees in online mentoring for girls in STEM. From this, we derive tentative indications of beneficial mentoring group compositions. However, the limitations of this study should be considered. Further studies replicating and broadening the results are needed.

DATA AVAILABILITY STATEMENT

The datasets analyzed for this study are not available due to reasons of data protection. Requests to access the datasets should be directed to MH, manuel.hopp@fau.de.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MH conceived the original idea, processed all the data, conducted all the statistical analyses, and wrote the manuscript. HS revised the manuscript. AZ and HS provided feedback and supervised the work. All authors reviewed the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.01929/full#supplementary-material

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Domain-Specificity of Educational and Learning Capital: A Study With Musical Talents

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The Education and Learning Capital Approach (ELCA) has been widely used to investigate talent development. A research gap is the implicit consideration of the domain specificity of educational and learning capital. In an empirical study with 365 school students we investigated the domain specificity of the approach for the domains of school learning and learning to play a musical instrument. At the beginning of the school year, students filled out a version of the Questionnaire for Educational and Learning Capital (QELC) for both domains and also responded to other domain-related measures (self-efficacy, grades). Six weeks later, students filled out a learning diary for 1 week in which they reported their activities on an hourly basis and responded to questions concerning these activities. Based on the Sociotope Approach this procedure helped to identify times in which students actually practiced their musical instrument, times that students could potentially practice their musical instrument (objective action space), and times that students would be expected to practice their musical instrument (normative action space). Three hypotheses were tested and could be supported. First, the availability of educational and learning capital for school learning and learning an instrument differed. Second, a confirmatory factor analysis supported the factorial validity of the domain-specific capital measurements. Third, domain-congruent correlations were mostly higher than domain-incongruent correlations, i.e., the availability of educational and learning capital for school learning correlated more closely with variables related to school learning than with variables related to learning a musical instrument. Similarly, the availability of the capitals for learning a musical instrument correlated more closely with variables related to learning a musical instrument.

Keywords: music, talent development, educational capital, learning capital, domain specificity

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INTRODUCTION

Two key insights on talent development are that people can differ substantially in both the speed of skill acquisition and the level of performance ultimately achieved (VanLehn, 1996; Ericsson et al., 2006; Shavinina, 2009; Attri, 2019). Since its beginnings, there has been a strong tendency in talent and giftedness research to explain these phenomena with domain-general concepts such as talents,

gifts, and IQ (Galton, 1883; Terman, 1925, 1954; Hollingworth, 1942; Howe et al., 1998). Even today, the echo of these beginnings is still noticeable, especially in practice. For example, in gifted identification, the general intelligence quotient – next to general performance indicators such as GPA – is still the most important indicator (Ziegler et al., 2018).

For decades, however, many studies have shown that human learning and action cannot be fully understood if the unit of analysis is the decontextualized individual (Leont'ev, 1978; Vygotsky, 1978; Scribner, 1984; Suchman, 1987; Lave, 1988; Norman, 1988; Newman et al., 1989; Salomon, 1993). The idea that not only talents and gifts are important, but also what the individual applies these talents and gifts to was taken up very quickly. Numerous new concepts were proposed. Gardner's conception of multiple intelligences exerted a great influence. He postulated seven and later even more domain-specific intelligences (Gardner, 1983, 1986; Gardner and Moran, 2006). Other researchers like Tannenbaum (1986), Gagné (1993), and Heller et al. (2005) or Subotnik et al. (2011) postulated not only specific abilities, but rather specified and included domains in their models of giftedness and talent development. For example, Heller et al. (2005) mentioned mathematics, natural sciences, technology, computer science, art, languages, sports, and social relationships as domains.

In addition to naming domains, the narrow focus on domain-general personality factors was broadened by researchers. With regard to the person and the environment (as well as their interaction), a more holistic perspective was adopted (for an overview refer to Stoeger et al., 2017a). Numerous researchers suggested non-intellectual personality traits that should be incorporated into conceptions of giftedness. Examples include bodily-kinesthetic and interpersonal abilities (Gardner, 1983), creativity and task commitment (Renzulli, 1986), secure self-concept and persistence (Tannenbaum, 1986). In a similar vein, some researchers have explicitly included environmental factors in their conception of giftedness. This usually took the form of social units such as family or peers or social settings such as school (Mönks, 1992). It was assumed that these personality traits and environmental factors then acted as catalysts (e.g., Gagné, 1993) or moderators (e.g., Heller et al., 2005), which are crucial in transforming talents and gifts into high performance levels in the domains.

The main outcome of these theoretical developments at the end of the last century was that three standards were set that are still widely in place today: The holistic view of the person, the incorporation of the environment, and the importance of person-environment-interactions (Pfeiffer, 2018; Pfeiffer et al., 2018).

A number of new conceptions of talent development have been proposed that respect these three standards, focusing particularly on the interaction between the individual and the environment (Ziegler and Stoeger, 2017a; Ziegler et al., 2017b; Lo et al., 2019; Mudrak et al., 2019; Crawford et al., 2020; Dai, in press). These models are in line with Csikszentmihalyi's dictum (1998), according to which creative eminence is no longer only localized in the person, but in the system of the person and her environment. Person and environment are in this sense no longer separate entities, but interacting components of systems. These systems contain as a central component, the particular domain in which eminence is achieved.

Still, the central question is how an individual within a certain environment can achieve extraordinary performance levels in a particular domain. One answer given by many researchers is the availability of resources (Chandler and Ziegler, 2017; Phillipson et al., 2017; Stoeger et al., 2017b; Vialle, 2017; Lafferty et al., 2020; Paz-Baruch, 2020). However, the only fully elaborated resource-oriented approach to talent development to date is the Educational and Learning Capital Approach (ELCA) proposed by Ziegler and colleagues (Ziegler and Baker, 2013; Vladut et al., 2015; Ziegler et al., 2017a; Ziegler and Stoeger, 2019). Strangely enough, although there are various studies that investigate the role of these resources for talent development in different domains (e.g., Debatin et al., 2015; Stoeger et al., 2017b; Ziegler et al., 2019), the question of the domain specificity of these resources has not been explicitly addressed so far. Filling this gap is the objective of our study.

Learning Resources in Talent Development

The Education and Learning Capital Approach starts from the observation that many aspects of talent development and eminence that have been scientifically studied do not occur randomly, but in clusters. The most comprehensive level of analysis where such clusters have been found so far is "Golden Ages" (Pfleiderer, 1877)[1]. There are two well-known examples for eminence clusters in the domain of music. The first cluster includes Albinoni, Haendel, Vivaldi, Caldero, Cimarosa, Galuppi, Hasse, Jommelli, Lotti, the Marcello brothers, Parpora, Quantz, the two Scarlatti brothers, and Tartini. They all were active in 18th Century Venice within a 50-year period. A second, contemporary example of an eminence cluster in the domain of music includes well-known musicians and bands from London during the third quarter of the 20th century, such as David Bowie, Cat Stevens, The Byrds, Kinks, Motorhead, Nirvana, The Police, The Who, Rolling Stones, Sex Pistols, George Michael, Phil Collins, Peter Frampton, Elton John and many others.

Clusters of eminence in music—and also in other domains—can not only be identified within certain time periods but also at many other levels of analysis, including:

- Places, i.e., famous musicians are not distributed geographically at random, but group in selected places such as thriving cities (Schich et al., 2014).
- Institutions, i.e., some institutions constantly and frequently produce eminent musicians such as the Meadowmount School of Music in upstate New York, which counts Yo-Yo Ma, Pinchas Zuckerman, Joshua Bell, and Itzhak Perlman among its students (Coyle, 2009).
- Mentors, i.e., some people mentor an amazing number of outstanding artists. One example is Don Grierson, who has worked with the Beatles, Kim Carnes, Kate Bush, Cliff Richard, Joe Cocker, and Tina Turner. He is also considered

[1]The term "golden ages" refers to periods of highest development of a culture or a heyday of a certain form of cultural creation.

the discoverer of Celine Dion and other major talents (Grierson and Kimpel, 2009).

- Masterpieces, i.e., some musicians are responsible for a disproportionate number of the most famous pieces of music. For example, The Beatles alone produced 23 songs from Rolling Stone's 500 greatest songs of all time (Rolling Stone, 2008). Furthermore, John Lennon, Paul McCartney and George Harrison are also listed as solo artists.

These examples illustrate that there are not only differences in talent and giftedness between individuals, in terms of how likely they are to achieve eminence, as was originally assumed in giftedness research. Obviously, there are also differences between clusters, such as certain times, places or institutions that are more likely to favor the development of eminence. But what distinguishes these clusters? The answer from resource-oriented talent researchers would be that learning resources are the distinguishing aspect. Anecdotal data both in biographical and historio-metric analyses (e.g., Ochse, 1990; Simonton, 1994, 1999, 2019; Csikszentmihalyi, 1996) as well as numerous studies within expertise and talent research (Ericsson et al., 2018; Shavinina, 2009; Paik et al., 2019; Subotnik et al., 2019) support this claim for a wide range of learning resources such as mentors, family background, and motivation. ELCA is an attempt to compile and theoretically integrate the multitude of information that learning resources play for talent development.

The Education and Learning Capital Approach was developed within the framework of the Actiotope Model of Giftedness (Ziegler, 2005). According to this model, the basic unit of analysis of talent development is the actiotope, i.e., the individual and the segment of the material, social and informational environment with which she interacts (Ziegler et al., 2013). In such an individual lifeworld or "actiotope," factors that enable successful talent development are understood as resources. They are therefore means to an end, the end being talent development (Ziegler et al., 2017a).

In ELCA, two types of resources are distinguished (Ziegler and Baker, 2013). Exogenous resources, which are located in the enacted environment, are called educational capital. Endogenous resources that are localized in the individual are called learning capital. ELCA postulates five forms of educational capital (economic, cultural, social, infrastructural, and didactic educational capital) and five forms of learning capital (organismic, telic, actional, episodic, and attentional learning capital). Definitions for each capital can be found in **Table 1**. Within the forms of educational capital and learning capital, economic educational capital and organismic learning capital play a special role. They are called proto-capitals (Ziegler et al., 2017a), because they must first be transformed into other capitals to promote talent development. For example, money does not directly promote talent development. However, it can be used to pay, for example, private teachers for music lessons, who then represent social educational capital. Music teachers, in turn, provide cultural and didactic educational capital and provide also access to and optimal use of infrastructural resources.

The role of educational and learning capital for talent development has been corroborated in numerous research studies. For example, in the domain of academic learning it has been shown that average students, high-performing students and underachievers differ in their resource profiles. Better talent development was associated with a more positive resource profile (Harder et al., 2015; Leana-Taşcılar, 2015b; Paz-Baruch, 2015, 2020; Vladut et al., 2015; Stoeger et al., 2017b; Ziegler and Stoeger, 2017b; Veas et al., 2018). Similar findings have been reported in other domains, including music, sports, and vocational success (Ziegler et al., 2014, 2019). In each of these studies, a domain-specific adaptation of the research material was used. It was implicitly assumed that a characteristic set of specific learning

TABLE 1 | Definitions of the various types of educational and learning capital according to Ziegler and Baker (2013).

Exogenous Resources		Endogenous Resources	
Type	**Definition**	**Type**	**Definition**
Economic educational capital	Economic educational capital denotes every kind of wealth, possession, money, or valuable that can be invested in the initiation and maintenance of educational and learning processes. (p. 27)	Organismic learning capital	Organismic learning capital denotes the physiological and constitutional resources of a person. (p. 29)
Cultural educational capital	Cultural educational capital denotes value systems, thinking patterns, models, and the like that can facilitate—or hinder—the attainment of learning and educational goals. (p. 27)	Telic learning capital	Telic learning capital denotes the totality of a person's anticipated goal states that offer possibilities for satisfying her needs. (p. 30)
Social educational capital	Social educational capital denotes all persons and social institutions that can directly or indirectly contribute to the success of learning and educational processes. (p. 28)	Actional learning capital	Actional learning capital denotes the action repertoire of a person; as such, it describes the totality of actions a person is capable of performing. (p. 30)
Infrastructural educational capital	Infrastructural educational capital denotes materially implemented possibilities for action that allow learning and education to take place. (p. 28)	Episodic learning capital	Episodic learning capital denotes the simultaneous goal-relevant and situation-relevant action patterns that are accessible to a person. (p. 31)
Didactic educational capital	Didactic educational capital denotes the assembled knowhow involved in the design and improvement of educational and learning processes. (p. 29)	Attentional learning capital	Attentional learning capital denotes the quantitative and qualitative attentional resources that a person can apply to learning. (p. 31)

resources must be available for successful talent development in each domain. This means, for example, that talent development in music, football, painting, and mathematics require different learning resources. In fact, however, the need for such domain-specific adaptations and the availability of domain specific resources for talent development has not yet been explicitly demonstrated for educational and learning capital. This research deficit will be addressed in our study.

CURRENT RESEARCH

During talent development, endogenous and exogenous learning resources co-evolve in a process of circular causality (Bateson, 1972; Ziegler and Stoeger, 2017a). The processing of exogenous resources changes the endogenous resources, while the endogenous resources couple back through actions. Resources are thus connected in a characteristic and distinctive way and their interactions are coordinated. Their functionality is measured by how they influence talent development in a domain (Ziegler et al., 2017a).

If one extends this perspective to learning resources for two different domains, mutual influences of learning resources of the two domains must be considered. A learning resource of one domain A can either have a positive (+) or negative (−) effect on talent development in another domain or no effect on talent development in that domain at all (±). In this reciprocal process, the learning resource itself can remain positive (+), negative (-) or unchanged (±) in its effects on talent development in the original domain. In principle, learning resources from two domains can thus have six different relationships to each other: neutral (± ±), synergetic (+ +), destructive (− +), catalytic (± +), explosive (+), allostatic (±) (for exact definitions of these relations, see Ziegler and Stoeger, 2019).

However, the mutual effects of learning resources from different domains on talent development will always be a mix. One example is learning for school and learning to play a musical instrument. The relation can be destructive, i.e., both domains hinder each other with regard to the resource of time. Time used for learning for school may be lacking for practicing the musical instrument and vice versa. On the other hand, learning a musical instrument can be advantageous for a good grade in the school subject music and vice versa, good music lessons at school can be supportive for learning a musical instrument. In this case, the relation would be synergetic. As these examples show, it can be assumed that although each domain has characteristic resource profiles, these profiles themselves may not be completely independent of each other.

In our study, we investigate the domain specificity of educational and learning capital as well as relations between educational and learning capital in different domains. In designing the empirical study, we were guided by several research strategic considerations. First, we assumed that each person has resources that are differently functional for learning in different domains. Thus, it can be the case that the very same resource would be a learning resource with respect to domain A, but not with respect to domain B. To empirically demonstrate such an effect, a within-subject-design has to be chosen, in which a person's learning is examined in two different domains.

We tried to find two domains, which, although needing different learning resources, are not too different. From a research strategy perspective this is important because if the need to take the domain specificity of learning resources into account can already be shown in rather closely related domains, then this also applies a fortiori to domains that are further apart.

We opted for the two domains of school learning and learning a musical instrument. The choice of these two domains was also based on the availability of measuring instruments. In a study like ours educational and learning capital for different domains should be assessed by comparable measuring instruments. A school-based version of the Questionnaire for Educational and Learning Capital (QELC; Vladut et al., 2013; Paz-Baruch, 2015; Arilena and Leana-Tacilar, 2016) and a parallel version formulated for the domain of learning a musical instrument were already available (Ziegler et al., 2014).

In summary, our research's strategic considerations led to the decision that students who play a musical instrument should work on both the school and music versions of QELC. This allows for the testing of three hypotheses on the domain specificity of learning resources and their effect on learning activities and learning outcomes:

- Hypothesis 1 (mean differences): Educational and learning capitals for school learning and learning to play a musical instrument should differ in their availability.
- Hypothesis 2 (factor structure): In a confirmatory factor analysis, educational and learning capital related to learning in school and leaning a musical instrument can be identified as latent factors.
- Hypothesis 3 (correlations): Domain-congruent correlations should be higher than domain-incongruent correlations, i.e., educational and learning capital related to school learning and leaning a musical instrument should correlate more closely with their respective domain-related measures indicating successful learning for school or a musical instrument (i.e., grades, self-efficacy, practice time). However, no different correlation is expected with regard to the school grade in music, since educational and learning capital for school learning and educational and learning capital for learning a musical instrument should have a comparable effect.

MATERIALS AND METHODS

Participants

A total of 365 students (222 girls and 143 boys; age: M = 13.1 years, SD = 2.27) from German schools volunteered to take part in the study. They all took musical instrument lessons organized by their school and were members of their school music orchestra. They had been playing their instrument for at least 2 years.

Measures

Educational and Learning Capital: School

Educational and learning capital for the domain of school learning was measured with the Questionnaire of Educational and Learning Capital (QELC; see Vladut et al., 2013). Various studies prove its excellent psychometric properties (Paz-Baruch, 2015; Vladut et al., 2015; Arilena and Leana-Tacilar, 2016). The QELC measures each of the 10 capitals with the help of five items. The items were answered on a 6-point Likert-type scales ranging from 1 (not at all true) to 6 (absolutely true). A sample item for the organismic learning capital subscale reads "Being physically fit also helps me to learn and study for school for long periods of time." A sample item from the economical educational capital subscale reads "My family spends more money on my schooling than other families do." All ten subscales had an acceptable reliability with Cronbach's alphas of at least 0.64.

Educational and Learning Capital: Music

To measure educational and learning capital for the domain of learning a musical instrument, we used an adapted version of the QELC (Ziegler et al., 2014) in which all items referred to learning a musical instrument (instead of learning for school). A sample item for the organismic learning capital subscale reads "Being physically fit also helps me to learn and study my musical instrument for long periods of time." A sample item for the economical educational capital subscale reads "My family spends more money on my learning a music instrument than other families do." The reliabilities of the reformulated scales were acceptable with Cronbach's alphas of at least 0.68.

Academic Achievements

The students reported their grades on their last report card for the main subjects of mathematics, German language, and first foreign language (which are considered to be of special importance), as well as their grades in music. In German, the highest possible grade is 1 and the lowest possible grade is 6, with a grade of 5 or worse indicating failure to reach the classroom goal.

Self-Efficacy School and Self-Efficacy Music

Due to time constraints, it was only possible to measure self-efficacy with single items. Self-efficacy for school learning and self-efficacy for learning a musical instrument were measured on a 6-point Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree). Sample items read: "If I want to, I can easily increase my school grades" and "If I want to, I can easily increase my music instrument performance."

Practice of the Musical Instrument

Diary studies must be particularly economical, especially taking into account time constraints. For this reason, surveys are typically limited to a few minutes (Reis and Gable, 2000; Bolger et al., 2003). According to Reis and Gable (2000), daily entries should not exceed 5–7 min. For this reason, single item measures are often preferred (van Hooff et al., 2007). Practice of the musical instrument was measured in line with the sociotope approach (Ziegler et al., 2017b). For 7 days students filled out a learning diary. They answered for every waking hour (except for school hours) what activity they had carried out (including practicing their musical instrument in minutes). For each activity (i.e., for each time slot of an hour), students filled out two single items that referred to their normative action space ("Have you been expected to practice your instrument?") and to their objective action space ("Would it generally have been possible for you to practice your musical instrument?") concerning practicing their musical instrument. Answers were given on a 10-point scale from 1 (absolutely not) to 10 (absolutely).

Data Collection

The QELC was administered at the beginning of the school year. School grades and self-efficacy were also measured at this time. The participants filled out the journal 6 weeks later. The reason for this time-delayed assessment was, first, that we wanted to rule out interferences between answering the QELC and the sociotope measures. Second, music-instrument lessons have been organized by the schools and restarted after summer holidays with the new school year. We assumed that after 6 weeks routines had been established.

Data Analysis

To examine our assumptions about domain specificity of educational and learning capitals we conducted a Confirmatory Factor Analysis (CFA) with the twenty capital subscales. We built four latent factors for the school learning and music versions of the educational capitals and the learning capitals. For the combined capitals we expected co-variances.

We used the software R 3.5.0 with the library lavaan 0.6-1 (Rosseel, 2012; Rosseel et al., 2018). The lavaan library offers several methods to fit a latent or manifest variable model. The CFA was estimated with Full-Information-Maximum Likelihood (FIML). To examine goodness of fit of the model Chi-square Fit Statistics, Root Mean Square Error of Approximation (RMSEA), Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) were used.

For validation purposes, we calculated simple correlations between the four capital scales and academic achievements, self-efficacy, and practice of the musical instrument.

RESULTS

Descriptive Statistics and *t*-Tests

Table 2 shows means, standard deviations and Cronbach's alphas of the capital scales in the school learning and musical instrument learning version. Our first hypothesis was that there will be differences in the availability of the capitals in the two domains. **Table 2** shows paired *t*-test results including Cohen's d. With the exception of cultural educational capital, students indicated that they had more educational capital for learning their musical instrument than for school learning. 2-tailed paired samples *t*-tests showed that the mean differences are statistically significant, economic educational capital, $t(364) = 6.54$, $p < 0.001$; didactic educational capital, $t(364) = 19.35$, $p < 0.001$; social educational capital, $t(364) = 8.37$, $p < 0.001$; infrastructural educational capital, $t(364) = 10.22$,

TABLE 2 | Descriptive statistics, Cronbach's alpha of Educational Capital (EC) and Learning Capital (LC) scales, and paired t-test results.

Type of Scale	School version			Music version			*Paired t-test*	
Scales	***M***	***SD***	***Cronbach's alpha***	***M***	***SD***	***Cronbach's alpha***	***t(364)***	**Cohen's *d***
Economic EC	4.42	0.95	0.73	4.70	0.95	0.80	6.54**	0.30
Didactic EC	3.86	0.95	0.77	4.89	0.79	0.75	19.35**	1.18
Social EC	4.09	0.85	0.67	4.45	0.84	0.68	8.37**	0.43
Infrastructural EC	4.20	0.81	0.74	4.62	0.79	0.74	10.22**	0.54
Cultural EC	4.30	0.84	0.64	4.18	0.94	0.75	−2.48*	0.13
Educational Capital	4.18	0.69	0.84	4.56	0.72	0.89	11.76**	0.55
Organismic LC	3.72	1.03	0.76	4.42	0.92	0.80	14.28**	0.74
Actional LC	4.19	0.84	0.73	4.55	0.81	0.79	8.26**	0.44
Telic LC	3.68	0.94	0.68	4.05	0.96	0.71	7.31**	0.38
Episodic LC	4.10	0.88	0.79	4.37	0.89	0.83	5.65**	0.30
Attentional LC	3.55	0.94	0.79	3.97	1.04	0.83	8.05**	0.43
Learning Capital	3.85	0.77	0.89	4.27	0.80	0.92	11.07**	0.54

*, *t-test is significant at the 0.05 level (2-tailed); **, t-test is significant at the 0.01 level (2-tailed).*

$p < 0.001$; cultural educational capital, $t(364) = -2.48$, $p < 0.05$. A very similar picture was found with learning capital. For all forms of learning capital, students indicated that they had more resources for learning the musical instrument than for learning for school, organismic learning capital, $t(364) = 14.28$, $p < 0.001$; actional learning capital, $t(364) = 8.26$, $p < 0.001$; telic learning capital, $t(364) = 7.31$, $p < 0.001$; episodic learning capital, $t(364) = 5.65$, $p < 0.001$; attentional learning capital, $t(364) = 8.05$, $p < 0.001$. However, after a control of Type I error by a Bonferroni adjustment, the mean difference in cultural educational capital reported by the students was no longer significant, $p > 0.1$.

Overall, the results of the *t*-tests clearly support our first hypothesis. Students possess different amounts of educational and learning capital in the two domains investigated.

Confirmatory Factor Analysis

In hypothesis 2 we assumed that in a confirmatory factor analysis the two domains of musical instrument learning and school learning can be distinguished. This expectation was confirmed for both educational and learning capital. However, in line with previous studies (Vladut et al., 2013, 2015) and theoretical considerations (Ziegler and Baker, 2013), we found it plausible that some types of capital correlated with each other because they draw on the same learning resources.

The model with the best model fit is shown in **Figure 1** and **Table 3**, which overall supports Hypothesis 2. To judge the fit of the model, the significant χ^2 can be ignored, because with 365 cases, we have a much higher number than the limitation of 200 cases, allowing to use the χ^2-test (Awang, 2015). The CFI in the range of 0.90 to 0.95 is acceptable (Brown, 2015) and the TLI close to 0.90 can be accepted if other fit indices are satisfactory. As the RMSEA is not above 0.10 and the SRMR is below 0.08, the model does not have to be rejected. Furthermore, the χ^2/df ratio is below 5.0 (Wheaton et al., 1977).

The model is consistent with the assumption that educational and learning capitals are domain-specific. Within both domains, the individual educational capitals form a latent factor which is to be regarded as general educational capital of the respective domain. The same applies to the learning capital. These form a latent factor in their respective domain, too, which can be regarded as general learning capital in a domain. The individual educational capitals of a domain load only on the latent factor of their domain and neither on the latent factor learning capital of the same domain nor on the latent factor of the other domain. This also applies to the individual learning capitals of both domains with regard to the latent educational capital factors.

With regard to the individual educational and learning capitals, however, there are some co-variances across the domain boundaries, but only for the same type of capital. This means that individual capitals, such as the economic educational capital for school learning and the economic educational capital for learning a musical instrument have an undirected relationship. This is also true for cultural educational capital, attentional learning capital, and organismic learning capital.

Correlations

In hypothesis 3, we assumed that educational and learning capital for school learning and learning to play a musical instrument correlate more closely with variables indicative of learning and learning outcomes in the respective domain. The correlations are shown in **Table 4**. To test whether two correlation coefficients differ significantly, Meng et al.'s z (1992) was used. Since we tested directed hypotheses, one-tailed testing was conducted.

With regard to school achievement, as expected, educational and learning capital for school learning correlated more closely with grades in mathematics, German language, and first foreign language than educational and learning capital for learning a musical instrument (educational capital for school learning vs. educational capital for learning a musical instrument: Math, $z = 1.93$, $p < 0.05$; German language, $z = 2.99$, $p < 0.01$; first foreign language, $z = 3.13$, $p < 0.01$; learning capital for school learning vs. learning capital for learning a musical instrument:

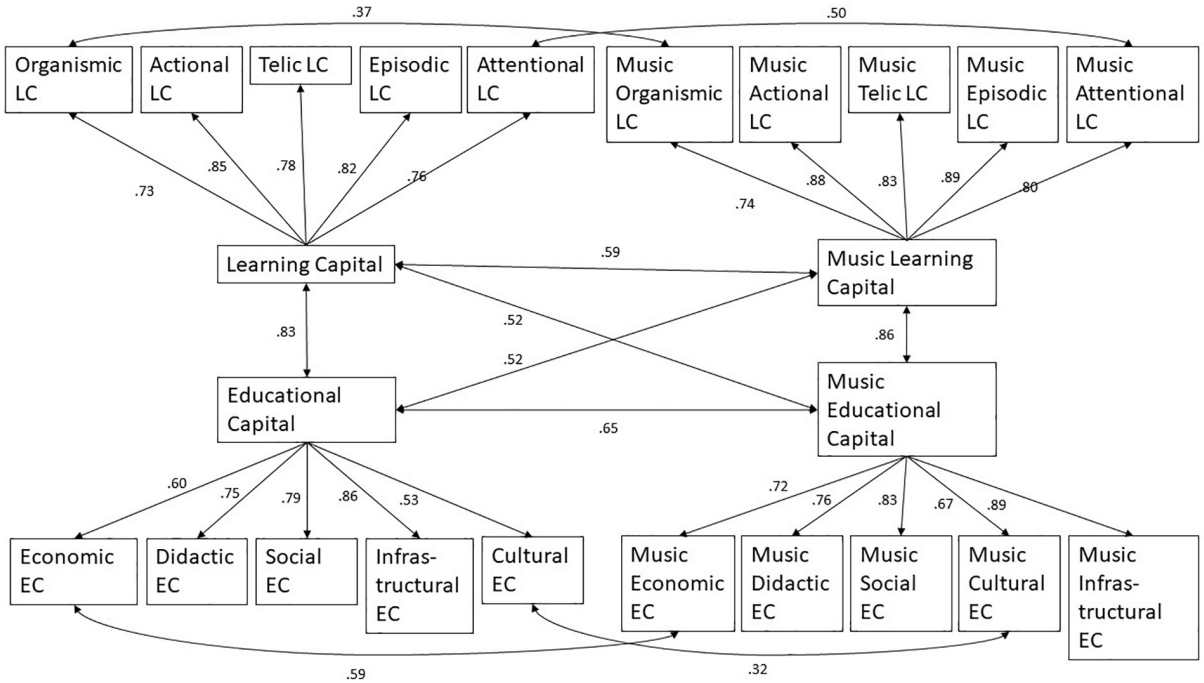

FIGURE 1 | Confirmatory factor analysis.

TABLE 3 | Results of the CFA.

χ^2	df	χ^2/df	*P* value (chi-square)	CFI	TLI	RMSEA	SRMR
658.898	159	4.144	0.000	0.909	0.891	0.093	0.054

TABLE 4 | Correlations between domain-specific versions of the QELC and indicators of learning in school and of the musical instrument.

	Educational Capital	Learning Capital	Music Educational Capital	Music Learning Capital
School grade in math	−0.138*	−0.245**	−0.047	−0.105
School grade in German language	−0.154**	−0.240**	−0.013	−0.030
School grade in first foreign language	−0.231**	−0.297**	−0.085	−0.124*
School grade in music	−0.097	−0.130*	−0.068	−0.103
Self-efficacy school learning	0.313**	0.425**	0.193**	0.295**
Self-efficacy musical instrument learning	0.332**	0.357**	0.459**	0.547**
Objective action space	0.110	0.024	0.301**	0.209*
Normative action space	0.081	0.056	0.212*	0.270*
Practicing time	0.214	0.151	0.228*	0.310**

**, Correlation is significant at the 0.05 level (2-tailed); **, Correlation is significant at the 0.01 level (2-tailed).*

Math, $z = 2.91$, $p < 0.05$; German language, $z = 4.33$, $p < 0.01$; first foreign language, $z = 3.63$, $p < 0.01$). Also as expected, the respective correlation coefficients did not differ significantly with regard to the grade in music; educational capital for school learning vs. educational capital for learning a musical instrument, $z = -0.61$, $p > 0.1$; learning capital for school learning vs. learning capital for learning a musical instrument, $z = -0.55$, $p > 0.1$.

The correlation pattern between the domain-specific versions of the QELC and self-efficacy of school learning and learning to play a musical instrument were also as expected. Availability of educational and learning capital for school learning was more strongly related to self-efficacy of school learning than to self-efficacy of learning a musical instrument, $z = 2.64$, $p < 0.01$, and $z = -2.90$, $p < 0.01$; while the availability of educational and learning capital for learning a musical instrument was more strongly related to self-efficacy of learning to play a musical instrument than to self-efficacy to learn for school, $z = -2.99$, $p < 0.01$ and $z = -4.45$, $p < 0.01$.

Finally, hypothesis 3 was also tested for practice of the musical instrument. In the learning diaries the students reported three aspects of their sociotopes with regard to learning the musical

instrument: Objective action space, normative action space, and practice time. As these were assessed related to music, educational and learning capital for learning a musical instrument should correlate more strongly with them than educational and learning capital for school learning. The hypothesis was supported albeit with one exception, and with significant results in the expected direction for educational capital school vs. educational capital musical instrument: Objective action space, $z = -4.14$, $p < 0.01$; normative action space, $z = -2.80$, $p < 0.01$; practicing time, $z = -0.31$, $p > 0.1$; Learning capital school vs. learning capital musical instrument: Objective action space, $z = -3.82$, $p < 0.01$; normative action space, $z = -4.48$, $p < 0.01$; practicing time, $z = -3.39$, $p < 0.01$.

In summary, it can be noted that 17 out of the 18 comparisons of correlations were in the expected direction, including the correlations between the domain-specific availability of educational and learning capitals with the grade in music, where no differences were expected. After Bonferroni adjustment, 15 out of the 16 expected correlational differences were still significant. We regard this as a confirmation of Hypothesis 3, which implies that a domain-specific assessment of educational and learning capital might result in improved predictions in future studies.

DISCUSSION

This work started from two theoretical premises. The first premise was that talent development is highly dependent on the availability of learning resources. On the one hand, this had been derived from the observation that clusters are observed on many levels of analysis (Ziegler and Baker, 2013). On the other hand, it was based on research studies which demonstrated the role of learning resources for talent development in general, and educational and learning capital in particular (Vladut et al., 2013, 2015; Paz-Baruch, 2015, 2020; Phillipson et al., 2017; Stoeger et al., 2017b; Vialle, 2017; Lafferty et al., 2020).

The second premise of this work was that there are specific ensembles of potent resources for specific learning goals and thus talent domains. Therefore, though there might be a substantial overlap of the resources needed for successful learning in one domain, these might not be identical with the resources needed to be successful in another domain. For example, the resources that lead to a successful learning career in school might not be identical to the resources needed for a successful learning career in music. This insight had been already implicitly taken into account within the ELCA. For example, if resources were investigated in a certain domain, the QELC was always adapted to the specific domain (Ziegler et al., 2014, 2019). What was missing, however, was a study that shows the different benefits of educational and learning capital for different domains.

Therefore, the goal of our study was to investigate the domain specificity of the ELCA. We decided to use a within-subject design. This allows more convincing demonstration that individuals use learning resources specifically for certain domains. However, this raises the problem of choosing appropriate domains. For reasons of expediency, we chose a domain in which everyone in our country participates, school-based learning in secondary education, and a domain in which many participate, learning a musical instrument. Two aspects are important in this decision to assess the relevance of the study.

First, the participants in our study were far from a degree of talent development that represents eminence. In terms of learning at school they had, on average completed only just over half of their schooling. Before eminence can be reached, or the extremely long periods of deliberate practice required can be achieved, many more years of engagement are necessary (Ericsson and Harwell, 2019). Similarly, the study participants were only at the beginning of the musical instrument lessons. Although they had been learning the instrument for at least 2 years, only very few children had had instrumental lessons for more than 4 years. This is also far from the time of practice considered necessary before eminence can be achieved (Ericsson et al., 1993). It can be assumed that the further that learning in a domain is from eminence, the less specialized it is (Debatin et al., 2015). If the need to take the domain into account can be shown at what is actually a fairly early stage of talent development, then this a fortiori applies to all later stages of talent development, which presumably require higher levels of specialization.

The second important reason for choosing the two domains was that although they are sufficiently different, they also share commonalities in terms of learning resources. The school organized the instrumental lessons, which in some cases meant that the school music teacher was also the music instrument teacher. The school's offer to learn a musical instrument was aimed primarily at students who were able to cope well with the school requirements, who had parental support in both domains and who were motivated for both domains themselves. The musical instrument lessons were designed to be compatible with the school in several ways, including the time of the musical instrument lessons, which took place in the school building. Finally, there was overlapping of content such as the ability to read notes. Thus, if even for domains with obvious overlapping of learning resources the need to take their specificity into account can be shown, then this applies a fortiori to other domains with less overlap.

Three hypotheses were tested in the study. The first hypothesis postulated that the learning resources for school learning and learning of a musical instrument differ in terms of availability. This hypothesis could be supported by simple mean value comparisons of the five forms of learning capital and the five forms of educational capital for the two domains. Although it was not an explicit hypothesis of our study, it is worth noting that nine of the ten mean comparisons indicated that students had more learning resources with regard to learning the musical instrument. This makes perfect sense, because accepting an additional offer from the school is particularly beneficial, if one expects successful participation.

The second hypothesis postulated the factorial validity of educational capital and learning capital in the domains of school learning and learning to play a musical instrument. To this end, a confirmatory factor analysis was conducted. The confirmatory factor analysis showed that educational and

learning capitals for school learning and for the learning of a musical instrument are different factors. As expected, the educational and learning capitals related to school learning and to learning a musical instrument each form a latent factor. Some plausible co-variances were found in individual education and learning capitals across the domain boundaries. However, this concerned the same type of capital in each case. Thus, economic educational capital, cultural educational capital, organismic learning capital, and attentional learning capital for school learning and learning to play the musical instrument may overlap. For example, some free hours in the afternoon are basically available for both academic learning and practicing the musical instrument.

In hypothesis 3, domain-congruent correlations were postulated between the capitals and various indicators of school learning and the learning of a musical instrument. As expected, educational and learning capital for school learning was significantly higher correlated with better grades in mathematics, in the German language and in the first foreign language than educational and learning capital for learning a musical instrument. The correlations of learning resources in both domains with music grades did not differ significantly from each other. This seems plausible, as grades in music seem to have a special status and resources from both domains might be useful for reaching good grades in the subject of music.

Domain-congruent correlations were also found for the capitals with regard to the self-efficacy of school learning and learning to play the musical instrument. As expected, educational and learning capital for school learning better predicted the self-efficacy for school learning and educational and learning capital for learning the musical instrument better predicted the self-efficacy for learning a musical instrument.

Hypothesis 3 also addressed several variables important from the perspective of the sociotope approach (Ziegler et al., 2017b): time spent practicing the musical instrument, time spent in situations where the students could potentially practice their instrument (objective action space), and times students perceived to be expected to or important for them to practice their instrument (normative action space). As expected the educational and learning capital for learning a musical instrument correlated more strongly with these variables than educational and learning capital for school learning, with one exception. Educational and learning capital for learning a musical instrument did not significantly correlate with the objective action space for practicing a musical instrument. A possible explanation for this unexpected finding might be an exceeded threshold value with regard to educational capital, i.e., exogenous learning resources. It seems feasible that parents only make the decision to allow their child to attend voluntary musical instrument lessons if exogenous learning resources are available in sufficient quantity. However, though the availability of exogenous learning resources might provide a sufficient objective action space for practicing a musical instrument, this does not automatically mean that it goes along with a normative expectation to use this opportunity (normative action space).

All in all, our study contains numerous findings that broaden the research on learning and educational capital and that support the domain-specificity of educational and learning capital with regard to talent development. However, our study also has various limitations.

A first limitation of our study lies in relying on self-reports from questionnaires and diaries. A more objective recording of resources would be definitely desirable. Also, some aspects in our study, especially in the diary study, were measured with single items. Here, too, a replication of our study with more reliable measuring instruments would be desirable.

A second limitation are the fit indices of the confirmatory factor analysis. Although they were still satisfactory, they were certainly not perfect. Therefore, a replication of the findings of our study would be desirable.

A third limitation of our study is the partial use of single items. However, it distinguishes between the learning in the two domains.

From a theoretical standpoint, a fourth limitation of our study lies in the fact that the domain specificity of learning resources was only shown for two domains, and at a rather early stage of talent development. To ensure the generalizability of our finding to other domains and other stages of talent development further studies are needed.

A final limitation lies in the fact that the design of our study does not allow conclusions to be drawn about the direction of influence between the variables under investigation. Although the recording of educational and learning capital was carried out weeks before the diary study, this does not indicate causality in the sense of educational and learning capital influencing the shape of dependent variables in the statistical analyses. Indeed, ELCA is committed to the concept of circular causality, which rejects such simple cause-effect relations (Bateson, 1972; Ziegler and Stoeger, 2017a) that, however, with a design like ours could not be investigated.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of local data protection regulations. Requests to access the datasets should be directed to Marold.Reutlinger@fau.de.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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BRIEF RESEARCH REPORT
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Boys-Specific Text-Comprehension Enhancement With Dual Visual-Auditory Text Presentation Among 12–14 Years-Old Students

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Quality of language comprehension determines performance in all kinds of activities including academics. Processing of words initially develops as auditory, and gradually extends to visual as children learn to read. School failure is highly related to listening and reading comprehension problems. In this study we analyzed sex-differences in comprehension of texts in Spanish (standardized reading test PROLEC-R) in three modalities (visual, auditory, and both simultaneously: dual-modality) presented to 12–14-years old students, native in Spanish. We controlled relevant cognitive variables such as attention (d2), phonological and semantic fluency (FAS) and speed of processing (WISC subtest Coding). Girls' comprehension was similar in the three modalities of presentation, however boys were importantly benefited by dual-modality as compared to boys exposed only to visual or auditory text presentation. With respect to the relation of text comprehension and school performance, students with low grades in Spanish showed low auditory comprehension. Interestingly, visual and dual modalities preserved comprehension levels in these low skilled students. Our results suggest that the use of visual-text support during auditory language presentation could be beneficial for low school performance students, especially boys, and encourage future research to evaluate the implementation in classes of the rapidly developing technology of simultaneous speech transcription, that could be, in addition, beneficial to non-native students, especially those recently incorporated into school or newly arrived in a country from abroad.

Keywords: language-comprehension, reading, listening, Secondary-school, gender, Spanish, sex-differences, dual-modality

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INTRODUCTION

New electronic devices offer easily accessible possibilities for students to simultaneously listen and read texts, and this may enhance reading comprehension in poor skilled students (Wood et al., 2018), or even in students at risk of exclusion for not knowing the official language, or children with auditory problems (Taufan, 2019).

Fluent understanding of written and audible verbal information is essential for school success. Difficulties in reading and listening lay behind low academic performance (Smagorinsky, 2001; Hornickel et al., 2011; Tierney and Kraus, 2013; Cox et al., 2014).

Modality of presentation refers to the sensor route for information processing, such as visual, auditory, or signed words (Penney, 1989; signed modality was not considered here). Determining the most efficient mode for text presentation (audio, visual text or both simultaneously) has been a subject of psychological and educational research (Wolpert, 1971; Green, 1981; Daniel and Woody, 2010); brain activation neuroimaging studies (Green, 1981; Buchweitz et al., 2009) and eye-tracking analysis (Gerbier et al., 2018; Conklin et al., 2020).

Regarding second language learning (L2), research indicates that reading-while-listening is helpful for comprehension, fluency, and vocabulary acquisition (Chang, 2009; Woodall, 2010; Chang and Millett, 2015). Concerning the effects of dual-modality in native languages, Penney (1989) reviewed a collection of memory experiments where sets of words presented in dual-modality produced enhanced memory recall in comparison to words presented in only one modality. Later, Montali and Lewandowski (1996) found that dual-modality benefited less-skilled students at reading social and science passages. In adults, recall after reading text has been reported to be superior to recall after just listening to text (Green, 1981; Dixon et al., 1982; Lund, 1991; Daniel and Woody, 2010). Daniel and Woody (2010) found a better understanding of texts presented for reading-only than listening and reading simultaneously, in young adults. Similarly, Moreno and Mayer (2002) found that adult students who read while listening showed a better comprehension than those who only listened or those whose text was shown with accompanying animations. On the contrary, several research reports have shown worse text comprehension in dual-modality in adults when reading passages of novels (Moyer, 2011; Rogowsky et al., 2016) multimedia narrations (Craig et al., 2002), or technical documents (Kalyuga et al., 2004).

Factors related to the effect of modality presentation are student diversity, age, executive functions performance, type of task, and variability of levels of difficulty (i.e., novels vs. science passages). For instance, possible benefits of a specific modality might be undetected with the presentation of too simple verbal information, not enough to challenge reading skills to a threshold. On the other hand, dual-modality could represent an excessive cognitive load (Kalyuga et al., 2004) and produce distractions when trying to understand very complex texts for which fluency might be interrupted by, for instance, the need to re-reading some parts.

Complex text information processing requires dedicated attention (Bosse and Valdois, 2009; Posner and Rothbart, 2014). Attention skills are highly variable across students regarding their socioeconomic status (Noble et al., 2005) and cognitive factors such as working memory or executive functions (Verhoeven et al., 2011; McVay and Kane, 2012). All these factors contribute to the high variability in reading comprehension among students but one of the most remarkable differences in reading comprehension is student's sex. Research and tests on reading comprehension consistently show that girls outperform boys in a wide variety of circumstances (Chiu and McBride-Chang, 2006; Logan and Johnston, 2010). We hypothesized that students with difficulties in reading, especially boys as compared to girls, might be specifically benefited by simultaneous audio-text while normally reading. Thus, we aimed at testing text comprehension in boys and girls with three different presentation modalities (audible text, visual text, or dual-modality) using a considerably complex standardized reading text designed for 12–14 years-old (from 7th to 8th grade) Spanish students (Cuetos et al., 2016).

Importantly, there are no studies on the effect of dual-modality presentation in Spanish. This is a relevant matter because opaque and transparent spelling languages might show different effects of dual-modality on comprehension (Tainturier et al., 2011; Kwok et al., 2017).

METHODS

Ethics Considerations

The study design was approved by the *Universidad Internacional de la Rioja* Ethics Committee amongst written informed consent obtained from each participant's legal representative. It was managed according to the criteria set by the declaration of Helsinki and local laws.

Participants

Participants were recruited from a private school in Madrid (Spain). Initially, a total number of 215 participants (94 boys and 121 girls) were selected from 7th to 8th grade (12–14 years-old) (M = 12.89; *SD* = 0.70). Participants included in the study met the following inclusion criteria: being educated in the designated school, not presenting neurological, sensorial, psychopathological or learning disorders, and not having performed the tasks before. However, during data collection, schools were closed due to the worldwide COVID-19 pandemic, thus, not all the students were able to perform all the tests. Therefore, the final sample included: 215 participants (94 boys and 121 girls) for the text comprehension test (PROLEC-R), 177 participants (77 boys and 100 girls) for the verbal fluency (FAS), and the coding test from the WISC Battery, and 150 participants (66 boys and 84 girls) for the attention test (d2).

Instruments

Reading Comprehension Test From the Assessment Battery of Readers Processes, Revised (PROLEC-R) (Cuetos et al., 2016)

The test includes 4 short texts, 2 expositive, and 2 narrative. For this study one of the expositive texts was chosen. The participants should read (or listen) the text in silence; when they are finished, the researcher asks them to put the text away and answer 10 open inferential questions about it. The test can be administered individually or in group format, in the present study the latter format was chosen. The maximum time to perform this test was 15 min. Correct answers are scored with 1 point and wrong

answers are scored with 0 points. The outcome measure used in this study was the mean of correct answers.

Verbal Fluency Test FAS (Buriel et al., 2004)

This test was used to assess the "Phonological fluency" and the "Semantic fluency" of the participants. For the Phonological fluency subtest, participants were instructed to generate as many words as possible beginning with letters "F," "A," and "S" within a 1 min period for each letter. For the Semantic fluency, participants were instructed to generate as many words as possible belonging to the "fruit and vegetable" and "animals" categories within a 1 min period for each category. In both fluency tests proper nouns such as people's city and country names, and the same word with a different suffix, were excluded. The outcome measures used in this study were the mean of words proposed for each category.

Coding Test From the WISC Battery (Wechsler, 2005)

This test is used to assess processing speed. In this study, according to the sample age, only the B form was used. Participants should write certain symbols below the example numbers. To complete the test, 2 min were allowed. The test can be administered individually or in group format. In the present study the latter format was chosen. Correct answers are scored with 1 point and wrong answers are scored with 0 points. The outcome measure used in this study was the mean of correct answers.

Attention Test d2 (Brickenkamp, 2007, Adapted to Spanish by Brickenkamp and Seisdedos-Cubero, 2012)

This test was used to assess selective attention. It consists of 14 lines, each containing 47 characters ("p" and "d" with 1–4 dashes arranged either individually or in pairs above and below the character), in total there are 658 items. The subject is required to scan across the line to identify and to mark all "d" with a total of 2 dashes, either above or below the letter. To complete the test 10 min were allowed. The test can be administered individually or in group format, in the present study the latter format was chosen. The outcome measures used in this study were (TR) the total number of items processed, (TA) the total number of correct answers, (O) the number of errors of omission (d's with two dashes that were not marked), (C) the number of errors of commission (marked d's with less or more than 2 sashes or p's), (TOT) total effectiveness of the test [TR- (O + C)] and (CON) concentration index (TA-C).

Grades in Spanish language were also collected to have knowledge of the student's school performance and their general level of reading and comprehension capacities.

Procedure

Tests were conducted on different days during January and February 2020. The tests for the assessment of attention (d2), phonological and semantic fluency (FAS), and processing speed (WISC) were conducted in the participant's own classroom. The text comprehension test was performed in the computer lab. In order to fulfill the aim of the study and measure text comprehension by auditory, visual or dual-modality; some adaptations of the test were necessary. The participants assessed for visual modality should read in silence the text shown in a Microsoft PowerPoint file as a presentation with slides running every 20–25 s (visual modality); the participants assessed for auditory modality listened to the text transcribed using an audio recording played through Microsoft Windows 10 default audio software, with a neutral masculine voice (auditory modality), and for the participants assessed for dual-modality, the two formats were set together. The computers used for the test were prepared as follows: one-third of the computers presented the visual modality, another third presented the auditory modality, and the rest of the computers offered the dual-modality presentation. The participants were asked to bring their own earphones due to hygienic reasons. After the text presentation, participants were addressed to a web link where a form was displayed with the text comprehension questions. They were adapted into a Google Form in which anonymization number, sex, age, class, and presentation modality were also requested. Correction of the test was carried out following the test scoring criteria.

Data Analysis

In a first step, we tested possible group differences in control variables such as attention, phonological and semantic fluency, and speed of processing. Descriptive statistics including mean, standard deviation and standard error were carried out. Secondly, descriptive analysis for language comprehension modality, including mean, standard deviation, standard error, minimum, maximum and confidence interval; were estimated. Regarding the aim of the study of comparing performance in text comprehension given the presentation modality, ANOVA and multiple comparison tests were accomplished. To check if any possible significant differences among the established groups for text comprehension correlated with differences in the grades of Spanish language, Pearson correlations were performed, and additional ANOVA and multiple comparison tests were conducted. Levene test for homocedasticity among Spanish language performance confirmed variances could be assumed to be the same. Subsequently, to test if gender can determine significant differences among the established groups for text comprehension, new ANOVA and multiple comparison tests were conducted. Significance level was 0.05 for all the analyses. Data analyses were conducted using the IBM® SPSS® Statistics 25 for Windows.

RESULTS

First, we analyzed the general performance of the sample to control the natural differences between the groups of students. Descriptive analysis of test results among all cognitive tasks applied to the sample was within age average (**Supplementary Table 1**). ANOVA tests and multiple comparison Bonferroni tests showed that groups did not differ significantly in relation to attention measurements (d2), phonological and semantic verbal fluency (FAS), and speed of processing (WISC subtest Coding)

(**Supplementary Table 2**). The following measurements provided a descriptive statistics overview of cognitive performance in boys and girls separately (**Supplementary Table 3**). Afterward, mean comparison *t*-tests for independent samples were conducted, revealing a sex difference for all cognitive tasks, however, while girls showed better results in phonological fluency ($p < 0.05$ in the 3 components) and speed of processing ($p < 0.05$), boys had a better performance in the d2 test ($p < 0.05$) (**Supplementary Table 4**).

The next step in the analyses was to examine the potential differences in text comprehension depending on the presentation modality (visual, auditory, and dual). Average of comprehension scores showed a non-significant enhancement of comprehension with dual-modality ($F = 2.44$, p = n.s.; **Table 1** and **Figure 1A**). When groups were separated by sex, a striking improvement in text comprehension was revealed in boys with dual-modality (**Figure 1B**; $F = 8.29$, $p < 0.000$). Bonferroni multiple comparison tests showed that text comprehension differed among auditory and dual-modality groups ($p < 0.005$), and between visual and dual-modality groups ($p < 0.005$). On the contrary, not even a small tendency of improvement with dual-modality was found girls ($F = 0.96$, p = n.s.; **Table 2** and **Figure 1B**).

Verbal comprehension in different modalities could be related to student performance at school. Thus, correlations between language comprehension and Spanish language grades (teacher's scoring) between experimental groups were analyzed. Interestingly, auditory comprehension showed a positive correlation with grades ($r = 0.38$; $p < 0.005$), while visual performance showed just a tendency ($r = 0.163$, $p < 0.19$), and dual comprehension presented a barely flat relation ($r = 0.101$, p = n.s.; **Figure 2** and **Supplementary Figure 1**). These results might indicate that low auditory comprehension in low performance students is compensated by visual text support. Remarkably, when descriptives and multiple comparison tests of grades in Spanish among different modalities of text presentation were conducted, the dual-modality group showed significantly lower grades than the auditory group (Bonferroni: $p = 0.007$). However, even in this situation (against our hypothesis because worse lower grades should relate to a decrease, not an enhance, of comprehension) visual support in dual-modality improved

TABLE 1 | Descriptive and mean comparisons of text comprehension in different presentation modality (visual, auditory, and dual).

Descriptives

Text comprehension

	N	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Min.	Max.
					Lower bound	Upper bound		
Visual	73	4.03	2.15	0.25	3.52	4.53	0	8
Auditory	74	4.23	2.08	0.24	3.75	4.71	1	8
Dual	68	4.78	1.99	0.24	4.30	5.26	1	9
Total	215	4.33	2.09	0.14	4.05	4.62	0	9

ANOVA

Text comprehension

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	21.1	2	10.57	2.44	0.089
Within groups	918.7	212	4.33		
Total	939.8	214			

Multiple comparisons

Dependent variable: text comprehension

Bonferroni

(I) Presentation modality	(J) Presentation modality	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
Visual	Auditory	−0.20	0.34	1.000	−1.03	0.63
	Dual	−0.75	0.35	0.100	−1.60	0.09
Auditory	Visual	0.20	0.34	1.000	−0.63	1.03
	Dual	−0.55	0.35	0.352	−1.39	0.29
Dual	Visual	0.75	0.35	0.100	−0.09	1.60
	Auditory	0.55	0.35	0.352	−0.29	1.39

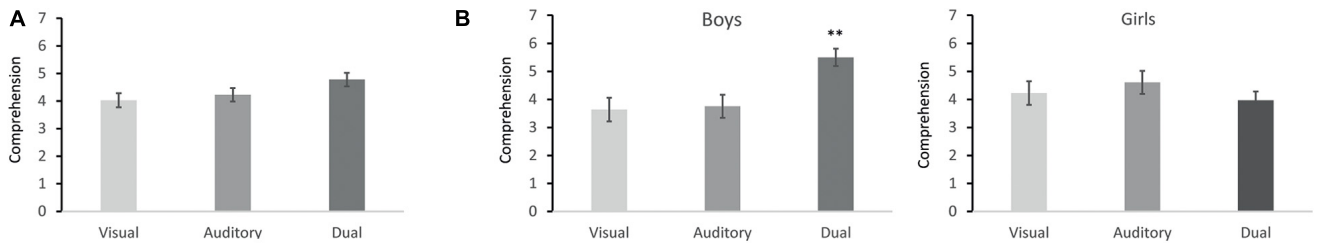

FIGURE 1 | Gender-specific language comprehension for different text presentation modalities. **(A)** Values represent the average score on text comprehension for each experimental group for all students. Error bars correspond to the standard error of the mean (n = 73, 74, and 68 for visual, auditory and dual groups). ANOVA analysis showed no significant differences among the groups (p = 0.0895). **(B)** Same analysis grouping boys and girls separately (**$p < 0.01$, Bonferroni among different modalities in boys).

comprehension above auditory (which had higher grades) (**Supplementary Table 5**).

As we found prominent differences between sexes in comprehension with dual-modality (**Figure 1**), we tested the correlation between text comprehension and grades in language for the three modalities separately in boys and girls. The analysis was suggestive but not conclusive due to the lower number of data with grades available due to the COVID-19 pandemic (see section "Methods"). Boys' comprehension in auditory modality showed a correlation coefficient of 0.38 with grades, but significance was borderline (p = 0.063; **Supplementary Figure 1A**). Similarly, in girls, the correlation coefficient for auditory modality was 0.30 but, again, not reaching significance (p = n.s.; **Supplementary Figure 1B**). When correlations were performed to examine the relation between sexes and modalities of presentation, they revealed interesting results. While for boys comprehension vs. grades showed a flat correlation (r = -0.105; p = n.s.), for girls, the correlation coefficient remained similar to auditory modality (r = 0.35; p = 0.06) (**Supplementary Figure 1**).

DISCUSSION

This work aimed to evaluate sex-differences in the comprehension of texts presented in auditive, visual, and dual modalities among 12–14 years-old girls and boys. The main finding is the prominent comprehension enhancement by dual-modality in boys, completely absent in girls. This striking difference between boys and girls might be explained by the faster development of girls (Etchell et al., 2018) and/or by differences in white matter connectivity, such as interhemispheric connectivity (Schmithorst et al., 2008). The finding that girls do not need dual text presentation modality for a normal comprehension could be explained by the observed increase in cognitive scores in girls in verbal fluency and speed of processing, consistent with other studies on this age (Anderson et al., 2001; Dekker et al., 2013) that reveal girls outperforming boys in some cognitive tasks. In addition, speech intelligibility and sentence comprehension in noisy classrooms are superior in 11–12 y-o girls as compared to boys (Prodi et al., 2019).

Intriguingly, our results show that boys perform better in attentional tasks. In dual-modality they must cope with two levels of information at the same time (dual-task), and this might be related to their higher attentional scores reported here. Interestingly, results in bilingual processing indicate that attentional control processing is involved in switching linguistic tasks (Costa et al., 2006), although this tasks-switch was between languages, not between audio/visual versions of the same text.

One of the findings in this work is the loss of positive correlation observed in dual-modality among comprehension and grades in the Spanish language, suggesting that dual-modality might help to compensate poor understanding of texts in students with low grades. This is consistent with several studies on English speakers, reporting that dual-modality aided less-skilled students (Montali and Lewandowski, 1996; Gerbier et al., 2018; Conklin et al., 2020). On the contrary, Rogowsky et al. (2016), did not find differences between dual and single modalities of verbal information processing in adults suggesting that age is relevant for the benefit of dual-modality in language performance, perhaps because it has been further consolidated as compared to children. In addition, the texts used by Rogowsky et al. (2016) were passages of novels, likely less demanding or more interesting than the standardized PROLEC-R used here, designed for the assessment of reading in the specific range of school-age (12–14 y-o).

Skilled readers might be distracted by listening while reading, for instance by forcing a visual or auditive inhibitory control. Our data do not reveal changes in that direction, although a more detailed study focused on good readers would be necessary to rule out the possibility. Our findings suggest that boys could improve speech understanding with the aid of available technology to immediately transcribe spoken text (Arend and Fixmer, 2018; Miner et al., 2020; Nguyen et al., 2020), for instance, on digital screens during teaching sessions. Noticeably, this is what many teachers have been doing traditionally by taking notes on the blackboard while talking (our work would support this classical practice, at least for boys). Obviously, the rapidness of manually transcribing speech on a blackboard is limited and requires additional attention, not always available.

Our results are clear regarding the lack of advantages of dual-modality in girls. However, more research needs to be done to determine whether dual-modality promotes any improvements in girls with low performance in their native language subjects. Nevertheless, even if dual-modality

TABLE 2 | Descriptive and multiple comparisons of text comprehension by presentation modality by sex.

Boys

Descriptives[a]

Text comprehension

	N	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Visual	25	3.64	2.05	0.41	2.79	4.49	0	7
Auditory	33	3.76	2.33	0.40	2.93	4.58	1	8
Dual	36	5.50	1.82	0.30	4.88	6.12	1	9
Total	94	4.39	2.23	0.23	3.94	4.85	0	9

[a]*Sex = boys.*

ANOVA[a]

Text comprehension

	Sum of squares	df	Mean square	*F*	Sig.
Between groups	71.6	2	35.80	8.29	0.000
Within groups	392.8	91	4.31		
Total	464.4	93			

[a]*Sex = boys.*

Multiple comparisons[a]

Dependent variable: text comprehension

Bonferroni

(I) Presentation modality	(J) Presentation modality	Mean difference (I-J)	Std. error	Sig.	95% Confidence interval	
					Lower bound	Upper bound
Visual	Auditory	−0.11	0.55	1.000	−1.46	1.23
	Dual	−1.86*	0.54	0.003	−3.18	−0.54
Auditory	Visual	0.11	0.55	1.000	−1.23	1.46
	Dual	−1.74*	0.50	0.002	−2.96	−0.52
Dual	Visual	1.86*	0.54	0.003	0.54	3.18
	Auditory	1.74*	0.50	0.002	0.52	2.96

[a]*Sex = boys.*

**The mean difference is significant at the 0.05 level.*

Girls

Descriptives[a]

Text comprehension

	N	Mean	Std. deviation	Std. error	95% Confidence interval for mean		Minimum	Maximum
					Lower bound	Upper bound		
Visual	48	4.23	2.19	0.31	3.59	4.87	0	8
Auditory	41	4.61	1.80	0.28	4.04	5.18	2	8
Dual	32	3.97	1.89	0.33	3.29	4.65	1	8
Total	121	4.29	1.98	0.18	3.93	4.65	0	8

[a]*Sex = girls.*

(Continued)

TABLE 2 | Continued

ANOVA[a]					
Text comprehension					
	Sum of squares	**df**	**Mean square**	***F***	**Sig.**
Between groups	7.67	2	3.83	0.96	0.383
Within groups	467.20	118	3.95		
Total	474.87	120			

[a] *Sex = girls.*

Multiple comparisons[a]						
Dependent variable: text comprehension						
Bonferroni						
(I) Presentation modality	**(J) Presentation modality**	**Mean difference (I-J)**	**Std. error**	**Sig.**	**95% Confidence interval**	
					Lower bound	**Upper bound**
Visual	Auditory	−0.38	0.42	1.000	−1.41	0.65
	Dual	0.26	0.45	1.000	−0.84	1.36
Auditory	Visual	0.38	0.42	1.000	−0.65	1.41
	Dual	0.64	0.46	0.524	−0.50	1.78
Dual	Visual	−0.26	0.45	1.000	−1.36	0.84
	Auditory	−0.64	0.46	0.524	−1.78	0.50

[a] *Sex = girls.*

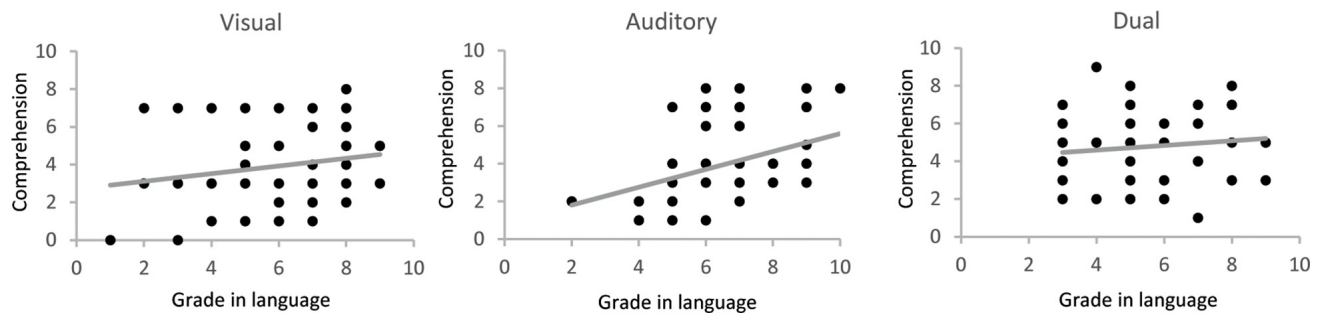

FIGURE 2 | Correlations between grades in language and verbal comprehension for different presentation modalities. Graphs show individual data for text comprehension and grades in Spanish native language. Every dot corresponds to a student with available grades (n = 64.53, 59, for visual, auditory, and dual groups). Some dots ovelap. Dotted lines are regression lines fitted to the experimental data with correlation coefficients and p-values, respectively, for each group: visual, r = 0.163, p = 0.19; auditive, r = 0.382, p = 0.004; dual, r = 0.101, p = 0.44.

was only helpful for boys, its use in academics should be taken into account, considering the poorer performance of boys as compared to girls at some educational levels (Steinmayr and Spinath, 2008).

Dual-modality benefits are under some debate. In addition to the use of low difficulty texts, previously unnoticed sex-differences, and perhaps age-differences, could explain the controversy. Regarding the age, text comprehension in young adults, men or women, do not seem to be aided by dual-modality, however, interestingly, more complex processing evaluated by transfer tests (which requires the use of text information to solve questions in other contexts) is better with dual-modality in men and worse in women (Flores et al., 2010). This report, together with our results supports the idea that the benefit of dual-modality in boys but not girls depends on age. We have not detected age-related changes in language comprehension, surely because of the short-range of age in our sample. The fact that Flores et al. (2010) detected transfer gender-differences in older subjects suggests that learning and developmental changes compensate for reading difficulties in boys only to some extent.

Friederici (2012) and recently Mossbridge et al. (2017), conducted researches where they predicted the support of cognition in dual or crossmodal visual-auditory signals by enabling the dynamic coordination of inner and sensory processes. This might suggest that receiving information using

diverse sensory pathways can enhance performance (Bulkin and Groh, 2006); in our results, the combination of visual displays and auditory information might have improved the performance of the group in general or benefit those students with the worst performance, as the dual-modality may have facilitated the task for them.

The implementation of speech transcription technology in classes would be relatively simple with commercially available software (Google Patents, 2020). However, an effort should be made to adapt a system that allowed (i) quick and easy activation and deactivation when speaking, (ii) integrated display independently of the programs being used during the class, (iii) remote control through a Bluetooth mouse or other device, and (iv) comfortable microphones. Despite these difficulties, the reality is that simultaneous speech transcription is already a reality in many conferences, and it is being further developed for simultaneous translation (Post et al., 2013; Bansal et al., 2017) and even psychological interviews (Miner et al., 2020).

In addition, worldwide changes due to the COVID-19 pandemic have enhanced the exploration of new devices for e-learning platforms and new options for students. Platforms for online teaching frequently lack sound quality, impairing correct understanding of verbal messages at the receptor site. Speech-to-text technology at the transmitter site could greatly contribute to solving this problem.

Moreover, online teaching during the pandemic lockdown in many countries has obliged students to invest a large visual effort at reading the information on screens. In addition to reducing eye strain (Rosenfield and Mcoptom, 2016), our results suggest that at least boys' reading comprehension would improve by simultaneous audio reading (quickly developing by different companies; i.e., Natural Reader, Nuance, Google, etc.).

Future plans involve adapting already available technology for simultaneous transcription of verbal information during classes and implement this technology at different educational levels from primary to university school, and finally, evaluate academic results, and student/teacher/family perception of these strategies. Additionally, this technology might be advantageous for students non-native in Spanish, especially those recently incorporated to school or newly arrived from abroad. These students might learn the new language faster, integrate more easily in the group and avoid the risk of being academically frustrated and delayed. Although dual-modality facilitation for second language learning has been extensively reported (Brown et al., 2008; Chang and Millett, 2014, 2015), the benefits for inclusion should be tested in natural conditions.

LIMITATIONS

The study was carried out with participants from a single center. Therefore, there may be variables contaminating the results and adversely affecting their generalization. The participants belonged to a middle-high socioeconomic status so the observed better reading performance in girls might not be present in lower levels. Further studies are required to verify this possibility.

Although we have measured the speed of processing with the WISC test, related to intelligence, we cannot rule out that some unexpected differences in intelligence among participants might explain the results to some extent.

Our results show slightly higher attention in some sections of the d2 test which might be related to the different performance of boys and girls in dual-modality. However, such a conclusion would require testing attention in the different modalities.

Attentional performance has been related to switching linguistic tasks (Costa et al., 2006). Another interesting future research would be to investigate the link between dual-modality and switching linguistic tasks.

Regarding the possibility that skilled readers might be forcing a visual or auditive inhibitory control in dual-modality, and therefore being harmed in their comprehension, would require a more detailed study focused on good readers.

A possible limitation of our work is that we used male voice for the auditive and dual modalities. Sex-differences could be related to this, however, voice acoustics differences have been reported to be quite similar among individuals and the general population (Lee et al., 2019). In addition, although differences in brain activity in response to female/male voices have been reported (Lattner et al., 2005), no evidence of differences among genders in auditive language perception with male or female voices have been reported (Mullennix et al., 1995; Lattner et al., 2005). In this work, the auditive text was presented with a male voice only, but indifferently to boys and girls.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The study design was approved by the Universidad Internacional de la Rioja Ethics Committee amongst written informed consent obtained from each participant's legal representative. It was managed according to the criteria set by the declaration of Helsinki and local laws.

AUTHOR CONTRIBUTIONS

Cd-l-P collected the data. MA-A and RS adapted reading comprehension test methodology and wrote the manuscript. Cd-l-P, ZO, and MA-A corrected the filled in tests. MA-A, ZO, and RS analyzed the data. MA-A, Cd-l-P, ZO, and RS designed research. All authors contributed with valuable comments along the research, including analysis and manuscript writing.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.574685/full#supplementary-material

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