Examination of the Yields of Growth Feedback from Science Teachers and Students' Intrinsic Valuing of Science: Implications for Student- and School-Level Science Achievement

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Abstract
Students' science knowledge and skills are considered critical to growing the intellectual capital on which societies rely to innovate and prosper. However, recent research has documented notable declines in students' intrinsic valuing of science and science achievement in Australia and other Western countries. As a result, there have been calls to investigate factors at both the student- and school-level that can improve intrinsic valuing of and achievement in science. Growth feedback from science teachers to students has been identified as one such factor. Growth feedback, which specifically targets individual student growth and improvement, is considered an effective form of teacher feedback. Because recent research has demonstrated the benefits of effective teacher feedback on intrinsic valuing of science and the positive link between intrinsic valuing of science and science achievement, the present investigation examined (at both the student- and school-level) the extent to which growth feedback in science predicts intrinsic valuing of science and the extent to which intrinsic valuing predicts science achievement and mediates the relationship between growth feedback and achievement. This study examined this hypothesized process with the 2015 Australian PISA sample (N = 14,530 students in N = 758 schools) via a multilevel structural equation model. Findings indicated that at both the student- and school-level, growth feedback significantly predicted intrinsic valuing, and intrinsic valuing significantly predicted achievement; growth feedback also had significant indirect effects of achievement via intrinsic valuing.
valuing. Taken together, our findings indicate that there are personal and whole-school yields for science achievement from the experiences of growth feedback in and intrinsic valuing of science.

KEYWORDS
feedback, growth, intrinsic valuing, motivation, PISA 2015, science achievement

1 | INTRODUCTION

Science adds to the intellectual capital on which societies rely in order to progress and prosper in critical areas of development and human services (e.g., medicine, technology, communications; Office of the Chief Scientist, 2012, 2014). Improving students' science knowledge and skills is therefore considered essential for the future research and innovation that underpins a society's competitiveness (Australian Academy of Science, 2006). Thus, targeting improvement in students' science outcomes has become a focal point of much research and policy (Van Aalderen-Smeets, Walma van der Molen, & Xenidou-Dervou, 2018; Watt et al., 2012). At the same time, however, declines in students' valuing of science and science achievement are evident in Australia (the site of the present study) and many other western countries (OECD, 2017a, 2017b). Students' intrinsic valuing of an academic subject is considered a critical catalyst for their learning and performance (Deci & Ryan, 2000; Wigfield & Eccles, 2000). Indeed, many theories of motivation position intrinsic valuing as a powerful antecedent of achievement (Bandura, 1997; Csikszentmihalyi, 1990; Deci & Ryan, 2000; Harter, 1978; Hidi, 2006; Locke, 1991; Wigfield & Eccles, 1992, 2000). Students who intrinsically value a subject, such as science, are more likely to engage in that subject, experience deeper learning, and achieve more highly (Vansteenkiste, Simons, Lens, Sheldon, & Deci, 2004; Wigfield & Eccles, 2000). As such, it is important to understand what can be done at both the student- and school-level, to support and foster intrinsic valuing of science and in turn, science achievement. Thus, in the present study we investigated one factor identified as critical to promoting students' science motivation and outcomes: teacher feedback (Chin, 2006).

Past research has demonstrated that the type, quality, and perception of teacher feedback plays a significant role in students' attitude toward, motivations for, and valuing of different academic subjects (Hattie & Timperley, 2007; Nicol & MacFarlane-Dick, 2006). Some research has shown that providing constructive and guiding information aimed at personal improvement is an essential component of effective feedback (Hattie & Timperley, 2007; Nicol & MacFarlane-Dick, 2006). Additionally, researchers have noted that teacher feedback can be more effective and beneficial when it addresses personal development and progress (Butler, 1987; Ferguson, 2011; Lizzio & Wilson, 2008; Weaver, 2006). We refer to this as “growth feedback.” Specifically, growth feedback explicitly identifies how and where students can improve their learning and is constructive for personal learning and growth (Martin, 2013).

Interestingly, there has been relatively little work examining the extent to which growth feedback impacts students' learning and motivation (Butler, 1987; Sansone, 1989). As a result, the impact of growth feedback is under-researched. Additionally, no research has apparently examined the role of growth feedback in science education. Given that growth approaches to other elements of student
learning (e.g., goal setting, assessment schemes, ability mindsets; Anderman, Gimbert, O’Connell, & Riegel, 2015; Dweck, 2012; Martin, 2006) have been found to positively impact student motivation and achievement in science (Grant & Dweck, 2003; Martin, Durksen, Williamson, Kiss, & Ginns, 2014), it is important to examine how growth feedback in science may impact students’ intrinsic valuing of and achievement in science.

To do this, a multilevel design that investigated links between these factors at the student- and school-level was used. At the student-level, we examined links between students’ perceptions of growth feedback provided by teachers in science, intrinsic valuing of science, and science achievement. At the school-level, we investigated links between school-average perceptions of growth feedback in science, school-average intrinsic valuing in science, and school-average science achievement. Whereas most research investigates science motivation and achievement at the student-level, the present investigation examined how these factors function at the broader school-level because school-level factors have been shown to impact whole-school intrinsic valuing of and achievement in science (e.g., Osborne, Simon, & Collins, 2003; Ruiz-Primo & Furtak, 2007). To the extent there are student- and school-level effects, individual and whole-school intervention and practice are signaled.

1.1 Intrinsic valuing and theories of motivation

Intrinsic valuing refers to the extent to which students value an academic subject based on their level of enjoyment and interest in that subject (Deci & Ryan, 2000; Wigfield & Eccles, 2000). Across numerous theories of motivation, students’ intrinsic valuing is considered a central predictor of learning and achievement (e.g., Bandura, 1997; Csikszentmihalyi, 1990; Deci & Ryan, 2000; Harter, 1978; Hidi, 2006; Locke, 1991; Wigfield & Eccles, 1992, 2000; for summary, see Schunk, Meece, & Pintrich, 2014a). For example, expectancy-value theory (EVT) contends that intrinsic valuing is one of the four subjective task values, which are posited as powerful explanatory factors of students’ performance (Eccles, 2005; Wigfield & Eccles, 2000). Moreover, EVT argues that students who intrinsically value an academic subject, such as science, are more motivated to perform well in that subject (Wigfield & Eccles, 1992, 2000). The intrinsic motivation construct within self-determination theory (SDT) is also considered cognate to intrinsic valuing (Deci & Ryan, 2000; Wigfield & Eccles, 2000). In SDT, intrinsic motivation refers to motivation that is derived from involvement in a task that is self-determined and engenders interest, enjoyment, and inherent satisfaction (Deci & Ryan, 2000; Ryan & Deci, 2000). SDT posits that individuals who are more intrinsically motivated for an academic subject are more likely to persist and experience deep learning in that subject (Ryan & Deci, 2000; Vansteenkiste et al., 2004). The concept of intrinsic valuing can also be seen in other seminal theories of motivation, such as (but not limited to) flow (Csikszentmihalyi, 1990), social cognitive theory (Bandura, 1997), models of mastery orientations (Harter, 1978), theories of interest development (Hidi, 2006), and goal setting theory (Locke, 1991), each of which argues that students’ interest in and enjoyment of a task—the core components of intrinsic valuing—will influence their academic outcomes.

Taken together, it can be seen that intrinsic valuing is a central explanatory feature of performance in many theories of motivation. Moreover, research spanning these theoretical paradigms demonstrates that intrinsic valuing is an important element of student achievement in science (Ainley & Ainley, 2011; Gottfried, 1985; Guo, Marsh, Parker, Morin, & Yeung, 2015; Nagy, Trautwein, Baumert, Köller, & Garrett, 2006; Watt et al., 2012). Based on this body of theoretical and empirical work, it is evident that intrinsic valuing is a critical antecedent of students’ science achievement. As such, it is important to examine teacher practices in science, as perceived by students that foster
its development (Schunk et al., 2014a). Teachers' growth feedback is posited as one such factor. Indeed, for example, EVT and SDT argue that students' social experiences, such as receiving teacher feedback, are likely to influence the development of intrinsic valuing (Ryan & Deci, 2000; Wigfield & Eccles, 1992, 2000). Thus, the present investigation sought to understand the extent to which students' reported experiences of growth feedback in science predicted their intrinsic valuing of science, and how their intrinsic valuing of science predicted their science achievement.

1.2 | Growth feedback

Teacher feedback is considered an essential component of the learning process (Butler & Winne, 1995; Nicol & MacFarlane-Dick, 2006; Sadler, 1989). The ultimate goal of teacher feedback is to convey the gap between a student's present and desired performance (Sadler, 1989) and to provide information about how to minimize this gap (Black & Wiliam, 1998). Indeed, Nicol and MacFarlane-Dick (2006) argue that quality feedback advises students on how to improve. As such, growth feedback can be considered a quality form of teacher feedback. Specifically, growth feedback is that which explicitly identifies how and where students can improve their learning, provides information that is constructive for personal learning, and motivates students toward continued personal growth (Burns & Martin, 2019; Martin, 2013). It is important to note that growth feedback is considered related to but conceptually distinct from other forms of teacher feedback. Although researchers have examined feedback along a variety of different axes (for summary see Ashford & De Stobbeleir, 2013), four consistently discussed forms are performance, motivational, attributional, and strategy (Schunk, Meece, & Pintrich, 2014b). Performance feedback provides students with objective and corrective information about task performance; motivational feedback provides students with information about competence and can often include social comparisons and bolstering messages; attributional feedback links task performance with student effort or ability; and strategy feedback informs students about how well a strategy is being applied or information about how to use strategies (Schunk et al., 2014b). Growth feedback, while not entirely dissimilar from performance and motivational feedback in that it provides students with information about task performance and competence, is nonetheless distinct in two important ways. First, unlike performance feedback, growth feedback moves beyond objective and corrective information to provide students with explicit guidance on improvement. Second, unlike motivational feedback, growth feedback focuses exclusively on personal growth and aims to provide targeted and specific feedback, rather than socially comparative or supportive messages. Thus, growth feedback is considered a distinct form of effective teacher feedback because it provides constructive information for personal improvement (Hattie, 2009; Martin, 2013). Indeed, previous research has demonstrated that such feedback positively impacts students' attitudes toward school, such as valuing, and academic outcomes (Hattie, 2009; Hattie & Timperley, 2007; Sansone, 1989).

Importantly, researchers have also demonstrated that students' perceptions of teacher feedback also play a role in their valuing and subsequent use of feedback (Price, Handley, Millar, & O'Donovan, 2010; Weaver, 2006; Wigfield & Eccles, 1992, 2000). Feedback that is vague, general, and not directly related to the task or personal improvement is perceived as ineffective and unhelpful (Ferguson, 2011; Lizzio & Wilson, 2008; Weaver, 2006). In contrast, researchers have found that students consider feedback to be the most beneficial when it is personalized, constructive, and provides guidance for personal development and growth (Ferguson, 2011; Lizzio & Wilson, 2008; Weaver, 2006). Additionally, researchers argue that feedback perceived as going beyond corrective or comparative information is more likely to sustain and support motivation in that area (Lizzio & Wilson, 2008; Weaver, 2006; Wigfield & Eccles, 1992, 2000). In this way, growth feedback is also likely to support motivation.
Although there has been no research to date about the role of growth feedback in science education, growth feedback may be aligned with formative assessment (Nicol & MacFarlane-Dick, 2006). Previous research has shown that formative assessment is an important component of promoting deep learning in science (Bell & Cowie, 2001; Cowie & Bell, 1999; Ruiz-Primo & Furtak, 2007). Moreover, formative assessment, especially if perceived positively by students, is considered an effective strategy for improving students' enjoyment of and interest in science (Osborne & Dillon, 2008). Thus, to the extent that this holds true for perceived growth feedback in science, it is likely that students who perceive growth feedback are more likely to enjoy and be interested in science—the essential components of intrinsic valuing of science. Additionally, growth approaches to other dimensions of student learning, such as growth mindset, have been found to improve students' valuing of science (Grant & Dweck, 2003). Taken together, it may be that growth feedback plays a similar role in supporting students' intrinsic valuing of science.

It should also be noted that while feedback (both perceived and objective) has been shown to play an important role in students' achievement, this mechanism, as per several motivational theories, is considered to be indirect (Deci & Ryan, 2000; Locke, 1991; Wigfield & Eccles, 1992; see also Ashford & De Stobbeleir, 2013; Hattie, 2009; Mouratidis, Michou, Aelterman, Haerens, & Vansteenkiste, 2018). For example, EVT contends that students' interpretation of feedback is likely to impact their subjective task valuing and ability beliefs, which in turn predict their achievement (Stipek & Mac Iver, 1989; Wigfield & Eccles, 1992, 2000). Similarly, SDT argues that constructive feedback, such as growth feedback, is considered a form of autonomy structure, and that autonomy structure supports achievement by strengthening students' intrinsic motivation (Deci & Ryan, 2000; Mouratidis et al., 2018). Drawing from these theories, the present investigation examined the indirect effects, more than the direct effects, of growth feedback on science achievement via intrinsic valuing.

1.3 Intrinsic valuing and achievement in science

As discussed above, intrinsic valuing is based on students' experience of enjoyment and interest. Within science, students who find science enjoyable and interesting are more likely to continue to engage and achieve in that subject (Goodrum, Druhan, & Abbs, 2012; Osborne et al., 2003). Indeed, extant research has demonstrated this link (e.g., Ainley & Ainley, 2011; Black & Deci, 2000; Chang & Cheng, 2008; Hoffmann, 2002; Simpson & Oliver, 1985; Singh, Granville, & Dika, 2002; Weinburgh, 1995). For example, Hoffmann (2002) (see also Häussler & Hoffmann, 2000) found that improving students' interest in science significantly increased their science achievement. Similarly, Oliver and Simpson (1988) demonstrated that students' enjoyment of science was a significant predictor of their science achievement throughout secondary school. Taken together, this indicates that interest and enjoyment, as the fundamental elements of intrinsic valuing of science, are important for science achievement. Thus, students who intrinsically value science tend to achieve more highly in science.

1.4 Intrinsic valuing and growth feedback in the school context

By and large, intrinsic valuing is considered an intrapsychic experience (Guo et al., 2015) and teacher feedback is considered an experience that takes place between the teacher and individual students (Black & Wiliam, 1998; Sadler, 1989). As it is critical to understand how students experience these factors, the bulk of research regarding these factors and processes has focused on the student-level (e.g., Chin, 2006; Guo et al., 2015), with less consideration for the contexts in which they are taught (Goodrum et al., 2012).
However, as relevant to these contexts, several theories of motivation argue that students' daily social contexts (e.g., school) are likely to impact their attitudes and beliefs, such as intrinsic valuing, about learning (Bandura, 1997; Pajares, 2006; Ryan, 2001). Within science, it may be that experiences of broader social support for science impact school-level intrinsic valuing of science. For example, previous work has shown that social and gendered messaging about how one should participate in science can impact students' intrinsic valuing of science (Nagy et al., 2006; Watt, 2004, 2006). Regarding growth feedback, previous research suggests that students' perceptions of teacher feedback play an important role in creating school motivational climates (Kuperminc, Leadbeater, Emmons, & Blatt, 1997; Reeve, 2009; Thapa, Cohen, Guffey, & Higgins-D' Alessandro, 2013), and school climate has been found to significantly impact students' motivation (Goodenow & Grady, 1993; Urdan & Schoenfelder, 2006; Wentzel, 1997). Extrapolating from this research, we suggest that school-level growth feedback—that is, the extent to which students' perceptions of growth feedback typically occurs within a school—will positively influence school-level motivation (viz., school-level intrinsic valuing of science). Given that intrinsic valuing of and achievement in STEM have also been found to be associated at the school-level (Yildirim, 2012), we hypothesize positive links between school-level growth feedback, school-level intrinsic valuing, and school-level achievement in science. Taken together, in examining the role of growth feedback in science and intrinsic valuing of science in students' science achievement, it is important to consider how these factors function at both the student- and school-level.

1.5 Covariates important to include in the investigation

The present investigation included multiple covariates at the student- and school-level that have been shown to influence teacher feedback in, intrinsic valuing of, and achievement in science. The following covariates were included at the student-level: age, gender, language background, socio-economic status (herein referred to as economic, social, and cultural status [ESCS]). Regarding age, previous work has demonstrated that students' intrinsic valuing of STEM tends to decrease over time (Watt, 2008). Research has demonstrated that there is a significant gender divide in science, such that boys are more likely to report higher valuing and engagement in science (Osborne et al., 2003; Watt, 2008). Language background and ESCS also play a role in students' attitudes toward STEM (Martin, Way, Bobis, & Anderson, 2015; Osborne et al., 2003; Simpkins, Davis-Kean, & Eccles, 2006).

The following covariates were included at the school-level: school location, type, size, school-average ESCS, gender composition, science teachers' educational qualifications, and school science resources. School characteristics, such as location, type, size, and gender composition, have been linked with students' science achievement (OECD, 2017a). Additionally, school-level ESCS has been found to play a role in achievement (Sirin, 2005). Regarding science-specific covariates, previous research has demonstrated that science teachers' educational qualification is linked to their use of feedback (e.g., formative assessment; Ruiz-Primo & Furtak, 2007) and school science resources are linked to students' valuing of science and science achievement (OECD, 2017a).

2 AIMS OF THE PRESENT INVESTIGATION

Science is a discipline fundamental to a society's capacity to progress, prosper, and innovate. At the same time, however, there is evidence of declining motivation and achievement in science throughout the secondary school years. In the present investigation, we sought to understand the extent to which students' experience of growth feedback in science predicted their intrinsic valuing of science, and
the extent to which these factors directly and indirectly predicted science achievement. Additionally, given that school-level factors have been shown to influence teacher feedback, students' intrinsic valuing, and achievement, in the present investigation, we examined the hypothesized model at both the student- and school-level. We did so by way of multilevel structural equation modeling to explore the following process: students' experience of growth feedback in science directly predicting intrinsic valuing of science, intrinsic valuing of science directly predicting science achievement, and intrinsic valuing of science mediating the link between growth feedback and achievement in science.

3 METHODS

3.1 Demographics of participants and schools

The present investigation was based on the Australian 2015 PISA data. The sample comprised a total of $N = 14,530$ students, who were clustered in $N = 758$ schools, with an average cluster size of approximately 19 students per school. The average age was $M = 15.78$ years old ($SD = 0.29$); it should be noted that although PISA samples are intended to comprise only students age 15, the range of the Australian sample was 15.25–16.33 years old. Approximately 49% of the sample was female and approximately 10% spoke a language other than English at home.

ESCS was assessed via the Index of Economic, Social, and Cultural Status. The ESCS is a weighted, standardized aggregation of the following indicators: parent education, highest parent occupation, and home possessions (e.g., books in the home). Because the ESCS is standardized across participating nations, scores greater than zero reflect higher than average ESCS. The average ESCS of the Australian sample was $M = 0.19$ ($SD = 0.82$), indicating that the Australian sample was slightly above the international 2015 PISA sample average.

Regarding the schools sampled, the average school size was $M = 993$ students ($SD = 460$). Approximately 59% of the schools were public and the majority (64%) of schools was located in urban areas (>100,000 people).

3.2 PISA sampling procedure and weighted scores

PISA uses a two-stage stratified sampling design that aims to capture nationally representative data. Stage one is school selection; schools in PISA are systemically chosen from a comprehensive list of schools within a given nation that have students aged 15. The schools listed are first grouped based on school characteristics (viz., strata) to improve the diversity of the sample, avoid selection bias, and reduce sampling variance (OECD, 2017b). From these groups, schools are selected based on the estimated proportion of PISA eligible students (e.g., age 15) within the school. Stage two is student selection. Students are randomly chosen from a complete list of all eligible students in the school. The target number of students per school (viz., cluster size) is 42 students (OECD, 2017b); however, cluster size varies across schools depending on the number of eligible students. Thus, to ensure that the results are not influenced by the variance of a school's student samples, PISA data are analyzed using weighted scores that adjust the data by school as a function of sample size. As a result, because of the variety of schools selected (e.g., variety of location, school type, and funding formats), the number of students sampled, the random sampling of students (viz., such that each student has equal odds of being selected), and the use of weighted scores, the PISA data are considered nationally representative.
3.3 | Procedure

The 2015 PISA student and school data were downloaded from the OECD database. The two data files were merged (via the school ID code provided) and cleaned (viz., recoded) where necessary. After the factors of interest were identified, a literature review was conducted to provide preliminary evidence for the hypothesized model. Numerous search terms were used domain-generally (in school in general), in relation to STEM subjects, and specifically in relation to science. For growth feedback, we searched for growth feedback, feedback, feedforward, improvement feedback, mastery feedback, self-improvement feedback, teacher feedback, positive feedback, and formative assessment. For intrinsic valuing, we searched for intrinsic valuing, intrinsic motivation, interest, and enjoyment. The following search databases were used: PsychNet/PsychINFO, educational resources information center, Google Scholar, and the archives of peer-reviewed science education and motivational research journals. Once evidence for the factors and hypothesized model were found within the literature, data analysis proceeded (see below for details).

3.4 | Materials

All measures used in this investigation were included in either the 2015 PISA Student Questionnaire or the 2015 PISA School Questionnaire. The Student Questionnaire was completed by students and the School Questionnaire was completed by the principals of the schools from which the students were sampled. The student and school data were matched via a school ID code provided in the PISA data. Descriptive statistics and reliability measures of the substantive factors (growth feedback in science, intrinsic valuing of science, and science achievement) are provided in Table 1; all statistics are reported for the student-level (Level 1; L1) and the school-level (Level 2; L2). Reliability is measured via coefficient omega ($\omega_h$), which is considered a robust measure of reliability for latent constructs; estimates above 0.65 indicate reliability (Dunn, Baguley, & Brunsden, 2014). As per the recommendations of Dunn et al. (2014), the coefficient omega estimates and 95% confidence intervals are reported in Table 1; coefficient omega estimates for all factors are reported here. Intraclass correlations were examined to determine if multilevel modeling was appropriate for the data. Intraclass correlation coefficient 1 (ICC1) was assessed to determine if factors varied significantly at the school-level; ICC1 values greater than 0.10 are considered to indicate educationally meaningful variance (Byrne, 2012). Here, we report the ICC1 values for each substantive factor (see also Table 1).

3.4.1 | Growth feedback in science

Students' reported experience of growth feedback (referred to herein as “growth feedback”) was assessed via two items from the Perceived Feedback Scale (“How often does this happen in <school science>? The teacher tells me in which areas I can still improve”; “How often does this happen in <school science>? The teacher tells me how I can improve my performance”). These items were selected from the five-item Perceived Feedback Scale due to their explicit focus on growth, via “improvement.” Other items in this scale focused on other forms of feedback, namely performance and strategy feedback. The items were measured on a scale of 1 (never or almost never) to 4 (every lesson or almost every lesson). This growth feedback factor was reliable at the student-level ($\omega = 0.92$) and school-level ($\omega = 0.99$). For growth feedback, ICC1 = 0.13, indicating significant variance at the school-level.

3.4.2 | Intrinsic valuing of science

Intrinsic valuing was measured as a higher order factor comprising an enjoyment and interest component. Enjoyment of science was assessed via the Enjoyment of Science scale (five items; e.g., “Disagree or...
agree with the statements? I have fun when I am learning <broad science>). The items were measured on a scale of 1 (strongly disagree) to 4 (strongly agree). The science enjoyment factor was reliable at the student-level (ω = 0.95) and school-level (ω = 0.99). Science interest was assessed via the Interest in Broad Science Topics scale (five items; e.g., “To what extent are you interested in: <specific science topic here>;” where each item specified a different area of broad science, such as “biosphere”). It should be noted that this scale was a new measure introduced in the 2015 PISA. The items were measured on a scale of 1 (not interested) to 5 (I do not know what this is). The items were then recoded such that scores of 5 were recoded as missing. The recoded scale was from 1 (not interested) to 4 (highly interested). The science interest factor was reliable at the student-level (ω = 0.83) and school-level (ω = 0.95).

As first-order factors, science enjoyment and interest were found to have high correlations at the student- and school-level (rs > 0.75) that might lead to collinearity. Based on this and that several theories of motivation that frame enjoyment and interest as part of an overarching intrinsic valuing construct (Deci & Ryan, 2000; Wigfield & Eccles, 2000), use of a higher order factor was considered a parsimonious solution. The science enjoyment items were used as indicators of a latent science enjoyment factor and the science interest items were used as indicators of a latent science interest factor. The latent science enjoyment and interest factors were used as indicators of a higher order intrinsic valuing of science latent factor. The higher order factor of intrinsic valuing demonstrated reliability at the student-level (ω = 0.86) and school-level (ω = 0.93). For intrinsic valuing, ICC1 = 0.12, indicating significant variance at the school-level.

### 3.4.3 Science achievement

Science achievement was measured via the plausible scores of the objectively measured Science Assessment component of the Student Questionnaire. The test design of PISA is based on variant matrix sampling, meaning that each student does not complete the entire assessment; rather, they complete different, yet overlapping, sets of assessment items (OECD, 2017b). Because of the underlying commonalities among the items, PISA is able to produce plausible values for students’ overall Science Assessment score via multiple imputations of the test items (for details about this procedure, see OECD, 2017b). For the 2015 PISA, 10 plausible values were generated for the Science Assessment (it should be noted that in previous years, PISA generated 5 plausible values; OECD, 2014). The plausible values are calculated such that they have a mean of 500 and a standard deviation of 100 for all OECD countries; thus, a mean less than 500 indicates science achievement scores lower than the OECD average (OECD, 2017b).

It is important to emphasize that the plausible values are not indicative test scores of individuals. They are random values drawn from students’ conditional distributions. As such, single plausible values cannot be used to compare individuals. Following OECD (2017b, see chapter 9; see also OECD, 2014) recommendations, to accurately assess students’ science achievement and its relation to

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Note. For achievement, the plausible values are calculated such the OECD mean is 500 (SD = 100).
other factors, each model was estimated 10 times, each using a different plausible value of science achievement. Thus, all coefficients, as relevant to achievement, discussed below (e.g., correlation and regression coefficients) are the averaged estimates from the 10 models. The plausible values demonstrated significant correlations ($rs > 0.92$), and the reliability of overall science achievement (as assessed via all 10 plausible values as indicators) was demonstrated at the student-level ($\omega = 0.99$) and school-level ($\omega = 0.99$). For achievement, ICC1 = 0.23, indicating significant variance at the school-level.

### 3.4.4 Student-level covariates

The following covariates were included at the student-level: age, gender, language background, and ESCS. Age was assessed as a continuous measure. For gender, females were coded as 0 and males were coded as 1. For language background, language of test (viz., English) spoken at home was coded as 0 and language other than test spoken at home was coded as 1. ESCS was assessed as a continuous measure. As described above, ESCS is a weighted, standardized aggregation of students' parent education, highest parental occupation, and home possessions with higher scores reflecting higher ESCS, and scores greater than zero reflecting an above average score for 2015 PISA.

### 3.4.5 School-level covariates

The following general covariates were included at the school-level: location, type, size, school-average ESCS, and gender composition. Location was assessed via the estimated population of the area in which the school was located; location was coded from 1 (<3,000 people) to 5 (>1,000,000 people). For school type, public schools were coded as 0 and private (independent) schools were coded as 1. School size was estimated as continuous variable. School-average ESCS and gender composition were assessed via the aggregated score for each school; this was done using the “cluster mean” function in Mplus.

As the present investigation focused on science specifically, alongside the general school covariates (above) it is also important to account for school-level covariates specifically relevant to science. The following two were included as school-level covariates: science teachers' educational qualifications and school science resources. For science teachers' educational qualifications, each school reported the percentage of science teachers (as relative to all science teachers) that had achieved ISCED 5A level (bachelor's degree) or higher, and who had a major in science; this was coded as a continuous variable. The average percentage was $M = 92\%$ ($SD = 0.18$). School science resources was assessed via the Index for Science Specific Resources. This index examined the amount of (e.g., “We have enough laboratory material that all courses can regularly use it”), quality of (e.g., “The material for hands-on activities in <school science> is in good shape”) and the school's willingness to spend funds on (e.g., “If we ever have some extra funding, a big share goes into improvement of our <school science> teaching”) science resources. It should be noted that the Index for Science Specific Resources was a new measure introduced in the 2015 PISA. The Index ranged from 0 to 8, with higher values reflecting more school-specific resources (viz., higher amounts, better quality, and more money spent); the average score was $M = 6.26$ ($SD = 1.39$).

### 3.5 Data analysis

The present investigation used multilevel modeling (MLM) to assess the extent to which growth feedback in science predicted intrinsic valuing of science, intrinsic valuing predicted science achievement, and intrinsic valuing mediated the relationship between growth feedback and achievement. The data were conceptualized as a two-level model, with students at the first level (L1) and schools at the
second level (L2). It is important to note that because MLM accounts for the hierarchical nature of the data (e.g., students within schools), it is possible to assess how individual factors (viz., student factors) and contextual factors (viz., school factors) impact student and school outcomes (Heck & Thomas, 2015). Moreover, MLM controls for variance between levels, such that L1 controls for L2 variance, and L2 controls for L1 variance, resulting in a model that explains unique variance at both levels (Heck & Thomas, 2015). Data analysis proceeded through four stages of analysis: reliability and tests of normality, multilevel confirmatory factor analysis (ML-CFA), multilevel structural equation modeling (ML-SEM), and indirect effects testing. As discussed previously, because of the use of plausible values, the ML-CFA, ML-SEM, and all tests of indirect effects were run 10 times, with the average of the 10 outputs (as relevant to achievement) presented as the final results in this study. All analyses were completed in Mplus version 7.2 (Muthén & Muthén, 2015).

3.5.1 ML-CFA and ML-SEM
ML-CFA was used to assess the factor structure and bivariate correlations of the hypothesized model. ML-SEM was used to assess the predictive strength of the parameters of the hypothesized model. The ML-CFA and ML-SEM included all covariates and substantive factors within a single model. Both models were estimated via maximum likelihood with robustness to non-normality (MLR; Chou & Bentler, 1995) and missing data were handled using full information maximum likelihood (FIML) (Arbuckle, 1996). Model fit was assessed via model fit indices, specifically the comparative fit index (CFI), root mean square error of approximation (RMSEA), and the standardized root mean square residual (SRMR); although the chi-square statistic is reported, it was not relied upon because it is sensitive to large sample sizes (Kline, 2016). Excellent fit was indicated by CFI values greater than 0.95 and RMSEA and SRMR values lower than 0.06; adequate fit was indicated by CFI values greater than 0.90, RMSEA and SRMR values less than 0.08 (Hu & Bentler, 1999; Schreiber, Nora, Stage, Barlow, & King, 2006).

At L1, for both the ML-SEM and ML-CFA, the substantive predictors were modeled via latent factors. At L2, the substantive predictors were modeled using composite scores to avoid inflated standard errors. Composite scores are considered a more parsimonious alternative to scale scores because they account for factor unreliability and measurement error (Kline, 2016). Composite scores were estimated using the following equation: \( \sigma_h^2 \ast (1 - \omega_h) \), where \( \sigma_h \) is the estimated variance of and \( \omega_h \) is the reliability estimate of the substantive factor (h) at L2.

3.5.2 Indirect effects testing
As outlined above, growth feedback in science was hypothesized to have an indirect effect on science achievement via intrinsic valuing of science at both the student- and school-level. These indirect effects were tested via two approaches. First, because bootstrapping is unavailable for multilevel data (Muthén & Muthén, 2015), bootstrapping was conducted in two separate single-level models. The first model examined the indirect effects at the student-level. The second model examined the indirect effects at the school-level; this was done by aggregating all substantive factors (including all plausible values) to the school-level. For both models, parametric bootstrapping (1,000 draws; Bollen & Stine, 1990) was used; additionally, to account for the fact that bootstrapping analysis assumes independent observations (Bollen & Stine, 1990), bias-corrected intervals are reported for both models. The second approach, as outlined by Preacher, Zhang, and Zyphu (2011), examined the indirect effects within the multilevel model. Although this approach only yields unstandardized betas, it accounts for the clustered nature of the data and was considered complementary to the first approach. The 95% confidence intervals are included for completeness.
4  |  RESULTS

4.1  |  Reliability and tests of normality

Growth feedback in science and intrinsic valuing of science were found to be approximately normally distributed at L1 and L2, based on standard deviation, skew, and kurtosis estimates (see Table 1). Because the calculation of the plausible values relies on the assumption of normal distribution of the PISA Science Assessment items, science achievement was also considered to be normally distributed (OECD, 2017b). As discussed above, growth feedback, intrinsic valuing, and science achievement were all found to be reliable at L1 and L2 (all $\omega_h > 0.85$).

4.2  |  Multilevel confirmatory factor analysis

The ML-CFA yielded adequate fit: $\chi^2 (112) = 2,962.10, p < 0.001$; CFI = 0.937; RMSEA = 0.042; SRMR L1 = 0.038, SRMR L2 = 0.029. The substantive predictors (growth feedback, intrinsic valuing) demonstrated strong factor loadings at L1 and L2 ($\lambda$s > 0.86). Reported here are all significant correlations as relevant to the proximal parameters of the hypothesized model. Table 2 reports all correlations (significant and nonsignificant) among the L1 and L2 substantive factors and covariates. It is important to note that, of the significant correlations, most of the correlation sizes (for both substantive and covariate correlations) were considered small to medium ($0.10 \leq r \leq 0.30$), with only one correlation (school-average ESCS to achievement) meeting the criteria of large effect size ($r \geq 0.50$; Cohen, 1988). At L1, growth feedback from science teachers was significantly correlated with students' intrinsic valuing of science ($r = 0.26, p < 0.001$) and intrinsic valuing was significantly correlated with students' science achievement ($r = 0.41, p < 0.001$). At L2, school-average growth feedback from science teachers was significantly correlated with school-average intrinsic valuing ($r = 0.17, p < 0.01$), and school-average intrinsic valuing was significantly correlated with school-average achievement ($r = 0.39, p < 0.001$).  

4.3  |  Multilevel structural equation modeling

The ML-SEM yielded adequate fit: $\chi^2 (114) = 3,146.71, p < 0.001$; CFI = 0.933; RMSEA = 0.043; SRMR L1 = 0.042, SRMR L2 = 0.031. Reported here and presented in Figure 1 are all significant substantive parameters at $p < 0.05$. Table 3 reports all significant and nonsignificant parameters. At L1, growth feedback from science teachers significantly predicted students' intrinsic valuing of science ($\beta = 0.23, p < 0.001$) and intrinsic valuing significantly predicted students' science achievement ($\beta = 0.35, p < 0.001$). At L2, school-average growth feedback significantly predicted school-average intrinsic valuing ($\beta = 0.24, p < 0.001$), and school-average intrinsic valuing predicted school-average achievement ($\beta = 0.16, p < 0.01$). This suggests that, at both the student- and school-level, experiences of growth feedback in science positively predict intrinsic valuing of science, and intrinsic valuing predicts science achievement.

Although not central to the investigation, here we report all covariates at L1 and L2 significant at $p < 0.001$. Regarding L1 covariates (viz., student-level effects), age ($\beta = 0.06$) and language background ($\beta = -0.09$) significantly predicted achievement, such that older students and students from English speaking backgrounds reported higher achievement. Gender significantly predicted perceived growth feedback ($\beta = 0.14$) and intrinsic valuing ($\beta = 0.06$) such that boys perceived more growth feedback and greater intrinsic valuing. Lastly, ESCS significantly predicted intrinsic valuing ($\beta = 0.20$) and achievement ($\beta = 0.27$), such that students from higher ESCS backgrounds reported more intrinsic valuing of and achievement in science. Regarding L2 covariates (viz., school-level...
effects), school-average intrinsic valuing ($\beta = 0.35$) and school-average achievement ($\beta = 0.57$) were significantly predicted by school-average ESCS, such that schools with a student body with higher ESCS scores had a higher school-average intrinsic valuing and school-average achievement.

### Indirect effects testing

Indirect effects testing assessed the extent to which growth feedback significantly predicted achievement via intrinsic valuing. Two complementary approaches were used. The first approach examined indirect effects in two separate single-level models (viz., bootstrapping tested in separate student-level and school-level models). The second approach (see Preacher et al., 2011) examined indirect effects in a single multilevel model. At L1, students’ experiences of growth feedback significantly indirectly predicted student achievement: first approach ($\beta = 0.08$, $p < 0.001$, 95% CI [0.08–0.09]); and second approach ($b = 10.51$, $p < 0.001$, 95% CI [9.28–11.74]). At L2, school-average growth feedback significantly indirectly predicted school-average achievement: first approach ($\beta = 0.03$, $p < 0.001$, 95% CI [0.03–0.03]); and second approach ($b = 6.57$, $p < 0.01$, 95% CI [3.03–10.11]).

### DISCUSSION

#### Findings of note

Science knowledge and skills underpin the research and innovation on which societies rely to improve and innovate in key areas of development and human services (e.g., medicine, technology, communications; Office of the Chief Scientist, 2012, 2014). However, declining science motivation and achievement has been a persistent challenge in Australia and other western countries (OECD, 2017a, 2017b).
As a result, there have been calls to investigate factors that can improve students' science motivation and achievement (Goodrum et al., 2012). The present investigation examined the extent to which students' experience of growth feedback in science predicts intrinsic valuing of science, and the extent to which intrinsic valuing predicts science achievement at both the student- and school-level. The investigation also examined the indirect relationship between growth feedback and achievement in science. Findings demonstrated that growth feedback in science positively predicted intrinsic valuing of science.

![FIGURE 1](image)

**FIGURE 1** Significant direct and indirect relationships at Level 1 (L1) and Level 2 (L2) among growth feedback in science, intrinsic valuing of science, and science achievement

As a result, there have been calls to investigate factors that can improve students' science motivation and achievement (Goodrum et al., 2012). The present investigation examined the extent to which students' experience of growth feedback in science predicts intrinsic valuing of science, and the extent to which intrinsic valuing predicts science achievement at both the student- and school-level. The investigation also examined the indirect relationship between growth feedback and achievement in science. Findings demonstrated that growth feedback in science positively predicted intrinsic valuing of science.

**TABLE 3** Standardized beta coefficients of hypothesized multilevel pathways

<table>
<thead>
<tr>
<th></th>
<th>Growth feedback</th>
<th>Intrinsic valuing</th>
<th>Achievement</th>
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<tbody>
<tr>
<td></td>
<td>L1</td>
<td>L2</td>
<td>L1</td>
</tr>
<tr>
<td><strong>L1 covariates</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>−0.03</td>
<td></td>
<td>−0.04*</td>
</tr>
<tr>
<td>Gender (M)</td>
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<td></td>
<td>0.06***</td>
</tr>
<tr>
<td>Language background</td>
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<td></td>
<td>0.03*</td>
</tr>
<tr>
<td>ESCS</td>
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<td></td>
<td>0.20***</td>
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<tr>
<td><strong>L2 covariates</strong></td>
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<tr>
<td>Location</td>
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</tr>
<tr>
<td>School size</td>
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<td></td>
<td>−0.03</td>
</tr>
<tr>
<td>Science Teachers' Ed. Qual.</td>
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<td></td>
<td>0.09</td>
</tr>
<tr>
<td>School science resources</td>
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<td></td>
<td>0.02</td>
</tr>
<tr>
<td>Gender composition</td>
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<td></td>
<td>0.01</td>
</tr>
<tr>
<td>School-average ESCS</td>
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<td></td>
<td>0.35***</td>
</tr>
<tr>
<td><strong>Substantive predictors</strong></td>
<td></td>
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</tr>
<tr>
<td>Growth feedback</td>
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<td>0.24***</td>
<td></td>
</tr>
<tr>
<td>Intrinsic valuing</td>
<td></td>
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</tr>
</tbody>
</table>

*Note.* ESCS: economic, social, and cultural status; M: male; Science Teachers' Ed. Qual.: science teachers' educational qualifications; *p < 0.05. **p < 0.01. ***p < 0.001.
and that intrinsic valuing positively predicted science achievement. Similarly, findings also indicated that growth feedback played a positive indirect role in science achievement via intrinsic valuing. These findings were reflected at both the student- and school-level.

At the student-level, these findings indicate that students who perceive growth feedback in science are more likely to experience greater intrinsic valuing of science, as well as (directly and indirectly) achieve more highly in science. At the school-level, these findings suggest that the school-average perception of growth feedback in science directly support school-average intrinsic valuing of science and indirectly support school-average achievement, and that school-average intrinsic valuing supports school-average science achievement. It may be that emphasizing growth in science, both at the student- and school-level, fosters personal and collective interest in and enjoyment of science, which in turn promotes higher science achievement. The findings of this investigation speak to the importance of growth feedback to individual students, whole-school yields of growth feedback, as well as the individual and collective experiences of intrinsically valuing science.

As discussed previously, the majority of research that has examined the impact of feedback and intrinsic valuing in science has focused on the student-level (Chin, 2006; Guo et al., 2015), with far less focus on how these factors function at the school-level. However, our findings showed that growth feedback and intrinsic valuing demonstrated significant school-level variance (viz., ICC1 > 0.10; Byrne, 2012). This suggests that students’ perceptions of growth feedback in and intrinsic valuing of science are likely to vary at both the student- and school-level. This being the case, it may be that some of the differences in students’ experiences of growth feedback in and intrinsic valuing of science can be explained by differences at both student-level and school-level. Thus, these findings indicate that it is important to examine how growth feedback and intrinsic valuing function beyond the student-level and to account for school-level factors that may impact them as well.

Our findings also provide evidence for the indirect mechanism by which growth feedback impacts achievement via intrinsic valuing, as proposed by several theories of motivation (e.g., Deci & Ryan, 2000; Locke, 1991; Wigfield & Eccles, 1992). As discussed above, theories such as SDT and EVT (Deci & Ryan, 2000; Wigfield & Eccles, 1992; see also Bandura, 1997; Locke, 1991) posit that feedback influences achievement by fostering students’ intrinsic valuing. Growth feedback in science, which entails structured and specific information that targets individual student improvement, aims to give students a roadmap for how to progress in science. By providing students with this constructive information (rather than information focused on objective or comparative performance), growth feedback is likely to bolster their interest in and enjoyment of science, which in turn supports their science achievement (Ashford & De Stobbeleir, 2013; Mouratidis et al., 2018). Indeed, our findings indicate this to be the case at both the student- and school-level. At the student-level, this suggests that intrinsic valuing may be a salient motivational mechanism by which growth feedback (and potentially other forms of feedback) can influence individual achievement. Importantly, our findings also indicate that this mechanism extends to the school-level, such that school-average intrinsic valuing of science mediated the relationship between school-average growth feedback and school-average achievement in science. Taken together, this suggests that intrinsic valuing, both personal and collective, may be an important component of a motivational mechanism that positively links growth feedback to achievement.

The findings also reaffirm the importance of examining student- and school-level socio-demographic factors. At both levels, gender was the most salient socio-demographic predictor of students’ experiences of growth feedback in science and ESCS was the most salient socio-demographic predictor
of intrinsic valuing of and achievement in science. Regarding growth feedback, student gender and school gender composition positively predicted growth feedback, indicating that boys and schools comprising more boys reported experiencing more growth feedback from science teachers. This finding may relate to the impact of gendered messaging in science education (Watt et al., 2012). Specifically, because boys are more often encouraged to pursue and excel in science than girls (Watt et al., 2012), they may be more likely to report experiencing feedback related to their growth and improvement. Future work might consider further examining the nature of this gender effect.

Student ESCS and the school-average ESCS positively predicted intrinsic valuing of and achievement in science, indicating that students from higher ESCS backgrounds and schools with a relatively greater proportion of high-ESCS students reported higher intrinsic valuing of and achievement in science. These findings thus reaffirm the critical role that student and school ESCS play in achievement (Sirin, 2005) and extend this understanding to science specifically. Notably also, beyond the effect of school ESCS, a school’s science resources significantly predicted science achievement. This suggests that investment in science resources may be one way schools can improve school-level science achievement. These findings also provide clarity about the relationship between ESCS and intrinsic valuing of science (Osborne et al., 2003). Our findings indicate that ESCS, at both the student- and school-level, plays a significant role in students' intrinsic valuing of science. It may be that high ESCS environments, either home or school, are able to communicate more support for the value of science via enhanced resources and resourcing, which has been found to impact students' personal valuing of science (Harackiewicz, Rozek, Hulleman, & Hyde, 2012). These findings speak to the importance of accounting for personal and structural socio-demographic factors that may impact students’ schooling experience at both the student- and school-level.

5.2 Implications for theory and research

The findings of this investigation hold implications for theories of motivation. As noted previously, numerous theories of motivation discuss the centrality of intrinsic valuing in students’ achievement (e.g., EVT, SDT, theories of flow). The findings of this investigation provide further evidence for this within science specifically. Our findings also indicate that the school-level experience of intrinsic valuing also plays an important role in school-wide achievement. Indeed, although most theories of motivation emphasize the individual experience of intrinsic valuing (and other forms of motivation), some do articulate the role of collective motivational factors (e.g., Bandura, 2000; Meece, Anderman, & Anderman, 2006). For example, SCT has identified that collective self-efficacy plays an important role in a group's ability to produce desired outcomes (Bandura, 2000; Skaalvik & Skaalvik, 2007). However, there has been limited work about the role of collective intrinsic valuing in achievement (but see e.g., Ryan, 2001), and no work (to our knowledge) has examined this within science. Our findings showed that intrinsic valuing demonstrated significant variance at L2 (ICC1 = 0.12), indicating that intrinsic valuing of science is likely to vary across schools. Moreover, our findings demonstrated that school-average intrinsic valuing of science played an important role in school-average science achievement. As such, our findings extend theorizing about collective motivational factors to intrinsic valuing specifically and indicate that the effects of collective intrinsic valuing warrant continued research.

As with intrinsic valuing, by and large, research that has examined perceived teacher feedback in science has done so at the student-level (Chin, 2006; Ruiz-Primo & Furtak, 2007). Although this work has provided valuable insight about the student experience of feedback, the findings of this investigation suggest that it is also important to examine school-level growth feedback in science. Researchers suggest that perceived feedback is an integral part of school climate (Kuperminc et al., 1997;
Reeve, 2009; Thapa et al., 2013). In this way, it may be that students’ perceptions of growth feedback help create a broader school climate that emphasizes growth in science. Similarly, because school climate impacts motivation (Goodenow & Grady, 1993), it may be the school climates that emphasize growth in science are better able to foster school-wide intrinsic valuing of science—as shown by the findings of this investigation. Thus, future research may consider examining school-level teacher practices, such as growth feedback, that support student learning and performance.

Our findings also suggest that there are yields in examining the type of teacher feedback perceived in science. Most work regarding teacher feedback in science has focused on the frequency and delivery of feedback (Chin, 2006; Ruiz-Primo & Furtak, 2007) with minimal work examining the motivational type or role of feedback. Indeed, to the authors' knowledge, this investigation is the first to examine the role of perceived growth feedback in science. The findings indicate that students’ experience of growth feedback plays a positive role in students’ science motivation and achievement, indicating that growth feedback is an important component of success in science. Given that positive teacher feedback has been shown to support other motivational processes in STEM (e.g., metacognition, goal setting, self-efficacy; DiBenedetto & Zimmerman, 2013; Martin & Evans, 2018; Senko & Harackiewicz, 2005), there may be yield in further disentangling how different types of feedback inform motivation. Indeed, it may be that different forms of teacher feedback in science have varying effects on science motivation and achievement (Nicol & MacFarlane-Dick, 2006). Continuing to study these effects may provide further insight on student motivation and achievement in science.

5.3 | Implications for teacher and school practice

Improving and sustaining student achievement in science is a challenge for many secondary schools (Goodrum et al., 2012). The present investigation identified two factors that may support student and school-wide achievement in science: growth feedback and intrinsic valuing. As discussed above, feedback is considered an essential component of the learning process in science (Bell & Cowie, 2001; Black & Wiliam, 1998; Chin, 2006; Ruiz-Primo & Furtak, 2007). To provide effective growth feedback, teachers should aim to answer the following three questions about each of their students: “where am I [viz., the student] going?” “how am I [viz., the student] going?” and “where to next [viz., for the student]?” (Hattie & Timperley, 2007). Teachers may consider addressing these questions as follows: reminding students of their individual learning goals and the importance of personal progress (“where am I going?”), providing explicit information about student progress on the task/learning goal and identifying where the student can improve (“how am I going?”), and sharing specific and practical strategies for improvement and growth (“where to next?”; Hattie & Timperley, 2007). At the school-level, school leaders may consider reminding teachers about the importance of using daily growth feedback. Because teacher feedback in part creates school climate (Thapa et al., 2013), there are whole-school yields in encouraging and supporting all teachers in their consistent use of growth feedback. It is important to note however that researchers who have tested interventions and programs that target teacher feedback (Akuma & Callaghan, 2018; Voerman, Meijer, Korthagen, & Simons, 2012) and school climate (Bradshaw, Koth, Thornton, & Leaf, 2009) have noted considerable challenges to long-term change, such as implementation fidelity and resistance to change. As such, it is important for teachers and school-leaders to consider approaches to growth feedback (such as those suggested here) that can be sustained and used consistently.

There are also strategies that teachers can use for promoting students’ intrinsic valuing of science. To improve students’ interest in and enjoyment of science, teachers may consider illustrating the
usefulness and relevance of science to students’ lives. Teachers can do this by (a) directly communicating this to students, or (b) providing students with tasks that have them explore and identify the personal relevance of science (Harackiewicz & Priniski, 2018). Although a combination of these strategies is suggested (Canning & Harackiewicz, 2015), the latter strategy has been found to be the most effective for all ability levels (Hulleman, Godes, Hendricks, & Harackiewicz, 2010). At the school-level, previous research has suggested that students’ interest and enjoyment of science can be influenced by broader social support for science (for review, see Hulleman, Thoman, Dicke, & Harackiewicz, 2017). Thus, school leaders may consider school-wide initiatives that help students see the relevance of science to their lives and communities and promote social engagement in science.

The socio-demographic findings also provide practical direction for teacher practice. As discussed above, the significant effects of gender and ESCS (here we focus on the student-level) indicate that different student groups, specifically girls and students from low ESCS backgrounds, may benefit from explicit attention. Regarding gender, boys were more likely to report receiving growth feedback than girls. When this finding is considered in the context of the gendered messaging that surrounds science participation (Watt et al., 2012), it may be that the feedback given is interpreted as more favorable to boys (viz., more growth feedback). Teachers may consider being more mindful of such messaging in class. Additionally, given that girls have been shown to benefit from increased support in science (Britner, 2008), science teachers may consider explicitly providing more growth feedback and other motivational supports to girls. Regarding ESCS, students from low ESCS backgrounds reported lower intrinsic valuing of science and science achievement than students from high ESCS backgrounds. This indicates that students from low ESCS backgrounds may benefit from increased motivational support in science. Indeed, Harackiewicz, Canning, Tibbetts, Priniski, and Hyde (2016) (see also Harackiewicz & Priniski, 2018) have shown that the motivation and achievement of students from low ESCS backgrounds improved with targeted motivation interventions in science. Science teachers may consider providing similar motivational support and structure to these students in their classrooms.

5.4 Limitations and future directions

The present investigation has some limitations that are important to consider when examining the findings and for future research. First, although PISA data are considered reliable, the measures used in this investigation, excluding the objective science achievement measure, were self-reported. Although students reporting on their perceptions of teacher feedback and on their own valuing of science are defensible approaches to data collection, self-report data do have some known limitations (e.g., Karabenick et al., 2007). Thus, future work may consider examining information from other sources. Second, the data were cross-sectional in nature; longitudinal data are required to confirm the hypothesized direction of the relationships tested. Notwithstanding this, modeling achievement as an outcome following feedback and motivation is well-established in theory and research as is the modeling of student responses (e.g., valuing) to teacher feedback (e.g., Locke, 1991; Mouratidis et al., 2018). It is important to note that this choice of ordering was also supported by the examination of alternative models. Third, the present investigation examined student- and school-level effects; PISA does not include classroom-level data and thus it is important to consider classroom-level effects in future work. Fourth, a variable-centered approach was used in this study; person-centered approaches may be considered in future to explore if different profiles of students’ receiving growth feedback and intrinsic valuing in science exist among students—as well as the achievement implications of these profiles. Lastly, this study examined the effects of growth feedback and intrinsic valuing in science; future work may investigate these effects in other academic domains. There is some
domain-specificity in motivation across school subjects (Green, Martin, & Marsh, 2007) and so the present multilevel model might be explored in other subject domains to ascertain the relative generality and specificity of the processes unearthed here.

6 | CONCLUSION

Increasing and sustaining students’ skills and knowledge in science is considered essential for the future innovation that supports societal advances (Australian Academy of Science, 2006). Thus, it is important to understand how to improve students’ motivation and achievement in science, as well as identify factors and mechanisms that may support students’ academic development in science. The present investigation examined the role of growth feedback in science and intrinsic valuing of science in students’ science achievement. The findings demonstrated that students’ experience of growth feedback in science is important for their intrinsic valuing of science and is also important for their science achievement by way of its positive effects on science valuing. Notably, these findings were reflected at both the student-level and the school-level. Taken together, then, personal and whole-school experiences of growth feedback and intrinsic valuing in science play powerful roles in science achievement.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

ENDNOTES

1It should also be noted that, although not a direct relationship of substantive interest in the hypothesized model, growth feedback was negatively correlated with achievement at L1 and L2. To examine this association further, growth feedback was correlated with different levels of achievement (at L1), as defined by the quartiles of plausible value 1. Findings of this analysis show that growth feedback was significantly negatively correlated with achievement for only the lowest achievement group \((r = -0.08, p < 0.001)\); the correlation was nonsignificant for all other groups \((p > 0.44)\).

2As the present investigation relied on cross-sectional data, alternative orderings were modeled to ensure the hypothesized model was the most appropriate for the data. Specifically, a model in which intrinsic valuing of science predicted growth feedback, and growth feedback predicted science achievement was assessed. This model demonstrated adequate fit: \(\chi^2(114) = 3,702.779, p < 0.001;\) CFI = 0.920; RMSEA = 0.047; SRMR L1 = 0.076, SRMR L2 = 0.039. However, the fit of this model was significantly worse than the hypothesized model. As such, the hypothesized model appears to be the most appropriate for the data.

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REFERENCES


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