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Structural relationships between classroom emotional climate, teacher–student interpersonal relationships and students' attitudes to STEM

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Abstract

Recently, integrated STEM projects have been introduced into school curricula in an attempt to increase students' understanding and interest in pursuing STEM subjects in senior high school and university. However, little is known about the classroom emotional climate in STEM classrooms and its effect, along with teacher–student interpersonal relationships, on students' attitudes towards STEM. A validated questionnaire about students' perceptions of the STEM classroom emotional climate and a simplified version of the questionnaire of teacher-student interpersonal relationships were administered to students completing STEM projects (N = 698). Students also completed a questionnaire about their attitudes towards STEM projects and continuation in the STEM pipeline. Structural equation modelling analysis suggested that the classroom emotional climate together with helping/friendly teacher-student interpersonal relationships have positive influences on student attitudes towards STEM. On the other hand, while teacher-student interpersonal relationships that are understanding or directing have a positive influence on the classroom emotional climate, they have negative influences on students' attitudes towards STEM and continuing in the STEM pipeline. There are some significant gender differences in teacher-student relationships that influence attitudes towards STEM. This raises some interesting possibilities about how teachers should manage classrooms that integrate STEM skills to complete projects in order to encourage greater participation in STEM subjects.

Keywords Classroom emotional climate · Attitudes to STEM · Integrated STEM education · Teacher–student interactions · Structural equation modeling

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Abbreviations

ACARA	Australian Curriculum, Assessment and Reporting Authority
CEC	Classroom Emotional Climate
CFI	Comparative fit index
ICSEA	Index of Community Socio-Educational Advantage
MITB	Model for Interpersonal Teacher Behaviour
PCA	Principal Component Analysis
QTI	Questionnaire on Teacher Interaction
RMSEA	Root Mean Square Error of Approximation
SEM	Structural Equation Modelling
SRMR	Standardised Root Mean Square Residual
STEM	Science, Technology, Engineering and Mathematics
TIMSS	Trends in Mathematics and Science Study
TLI	Tucker–Lewis Index

1 Introduction

Over the past decades, concern has grown in Australia regarding the declining numbers of students choosing Science, Technology, Engineering and Mathematics (STEM) subjects such as higher-level mathematics, physics and chemistry in the final years of high school or continuing to study natural sciences, engineering, computing and mathematics at university (Office of the Chief Scientist, 2016). This decline, together with the relatively low participation rate of women in STEM careers (Koch et al., 2014) has led to a focus on research into the possible causes of this decline and strategies to improve participation (e.g. Eccles & Wang, 2016; Riegle-Crumb et al., 2011; Sahin et al., 2017; van den Hurk et al., 2018). Students' attitudes towards STEM and their stated intentions to continue in the STEM pipeline have been shown to influence later participation in STEM subjects and careers (Kjærnsli & Lie, 2011; Potvin & Hasni, 2014). A longitudinal study of students' attitudes to school and STEM subjects during Year 7 showed that the strongest association between attitudes and intention to continue studying STEM subjects was between students' beliefs in these subjects' relevance and personal usefulness, although enjoyment and self-efficacy also predicted intentions (Kennedy et al., 2020). In an attempt to increase students' understanding of the relevance and importance of STEM careers to twenty-first century living and hence increase students' interest in studying STEM subjects and embarking on STEM careers, there has been an international move towards integrating STEM domains within the classroom (Honey et al., 2014).

When integrating STEM in schools, ill-structured problems often require students to use skills from a number of learning areas, such as mathematics, computer technology, science and engineering (Nadelson & Seifert, 2017). Integrated STEM projects can be short-term inquiry or design-based activities which are part of Mathematics/Science/Technology classes or longer-term projects which are stand-alone electives (English, 2016). These projects could be individual but more frequently involve collaboration in teams (Thibaut et al., 2018). Several studies have shown

that participation in integrated STEM classes improves students' attitudes towards STEM and the likelihood of students enrolling in university STEM courses (Koul et al., 2018; Means et al., 2016; Moote, 2020; Sahin et al., 2017).

However, there is limited understanding about what takes place in the integrated STEM classroom and what kind of teacher–student interactions foster interest in STEM. In STEM classrooms, are there relationships between classroom emotional climate, students' interactions with the teacher, and students' attitudes towards participating in integrated STEM classes and continuing to study STEM subjects? Do certain teacher–student interactions foster females' interest in STEM or are these interactions independent of gender? The research reported in this article provided tentative answers to these questions.

2 Literature review

2.1 Learning environments and classroom emotional climate

A major predictor of students' affective and cognitive outcomes is the student-perceived environment within classrooms (Fraser, 2012, 2014, 2019). Social and emotional interactions between the teacher and students and among students strongly influence engagement and learning (Pianta et al., 2008; Reyes et al., 2012; Urdan & Schoenfelder, 2006) and are consistent predictors of students' attitudes towards studying STEM and careers in STEM (Khine, 2015; Talton & Simpson, 1987). When teachers are caring and concerned towards students, take into account students' points of view, encourage cooperation and respect, are aware of students' learning needs, and foster supportive interactions between students, the classroom emotional climate is said to be positive (Hamre & Pianta, 2007).

Instruments developed to evaluate classroom emotional climate include the Classroom Assessment Scoring System (Pianta et al., 2008) and the Tripod 7Cs (Ferguson, 2010). However, these instruments do not fully capture the unique characteristics of integrated STEM classrooms. The *Classroom Emotional Climate* (CEC) questionnaire (Fraser et al., 2021) was developed and validated specifically to probe students' perceptions of integrated STEM classrooms. Seven scales make up the CEC questionnaire: *Care, Control, Clarity, Challenge, Motivation, Consolidation* and *Collaboration*. We hypothesised that a positive emotional climate within integrated STEM classrooms also would predict students' attitudes towards STEM and willingness to continue in the STEM pipeline based on the positive correlation between each of the CEC scales and students' attitudes to STEM reported by Fraser et al. (2021).

Although our study focused on classroom environment factors because of our interest specifically in classroom emotional climate and alterable classroom characteristics that teachers can address to support students—many other important factors also influence students' outcomes including attitudes. For example, Walberg's theory of educational productivity identifies nine such factors: three student attitudes (ability, development, motivation); two instructional variables (quantity, quality); and four educationally-stimulating psychological aspects (class environment, home

environment, peer-group environment, mass-media environment) (Fraser et al., 1987; Walberg, 1981). Social-cognitive models (e.g. Bandura et al., 2001) suggest that social relationships with parents and peers (as well as with teachers) influence students' attitudes and self-efficacy. In a study of classroom-, home- and peer-environment influences on student outcomes in science and mathematics involving 7000 students in 200 schools in Ohio, Fraser and Kahle (2007) reported that each of these three environments accounted for a statistically-significant amount of unique variance in student attitudes, but only the class environment accounted for statistically-significant amounts of unique variance in student achievement.

2.2 Teacher–student relationships

Classroom learning environment research has also included a focus on teacher–student interactions and relationships (van Tartwijk et al., 1998; Wubbels & Brekelmans, 2012; Wubbels et al., 2014). Brekelmans et al. (1990) investigated teacher relationships in classrooms from a systems perspective, adapting a theory of communication processes in which the behaviour of the teacher is influenced by the behaviour of students and this, in turn, influences student behaviour. Wubbels extrapolated seminal interpersonal behaviour research of Leary (1957) in developing the Questionnaire on Teacher Interaction (QTI), which is based on a Model for Interpersonal Teacher Behaviour (MITB) (Wubbels et al., 1985). The MITB has two overarching dimensions: agency (dominance or submission) and communion (cooperation or opposition), for assessing students' perceptions of eight types of teacher–student relationships that currently are labelled as Directing, Helping/friendly, Understanding, Compliant, Uncertain, Dissatisfied, Confrontational and Imposing (Wubbels et al., 2016). Figure 1 describes the way in which these teacher–student behaviours fit within the agency or communion dimensions. For instance, teacher–student interactions that are directing show strong teacher dominance of and moderate cooperation with students, while interactions which are understanding show more teacher submission to what students' want than dominance over them and

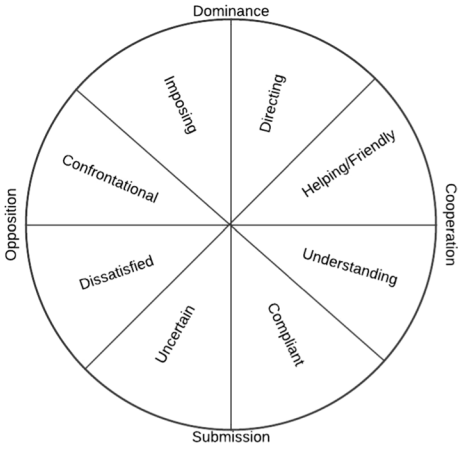

Fig. 1 Domains of teacher–student interactions of the MITB

more working in cooperation with students than opposing them. The QTI is made up of items describing each of these teacher-student interactions.

Generally, student outcomes are associated positively with more directing, helping/friendly and understanding relationships and negatively with more confrontational, dissatisfied and uncertain relationships with teachers (Koul & Fisher, 2005; Roorda, 2011; Wubbels & Brekelmans, 2012). Researchers have investigated associations between teacher–student interpersonal relationships and attitudes towards science in various countries, including the Netherlands (den Brok et al., 2004), Australia (Fisher et al., 2005), India (den Brok et al., 2005) and Turkey (Telli et al., 2010). In general, teacher–student interpersonal behaviours that are both dominant and cooperative (i.e., teachers with directing or helping/friendly behaviour) are linked to positive student attitudes to science but moderate negative correlations are found for uncertain teacher–student interpersonal behaviour. Also, a small positive association was found between compliant teacher–student behaviour (i.e., giving students a lot of freedom) and positive attitudes towards science. For instance, in an Australian study of biology students' perceptions on the QTI, Fisher et al. (1995) showed that directing, helping/friendly and understanding teacher–student interrelationships were positively related with students' attitudes towards science and to laboratory work. In Singapore, a similar pattern of relationships was reported between teacher–student interactions involving cooperation with students and positive attitudes towards mathematics among primary-school students (Goh & Fraser, 1998).

Telli et al.'s (2010) study in Turkey which used a Turkish version of the QTI, however, identified a negative relationship between the degree of cooperation displayed by the teacher and students' attitudes towards science inquiry. They suggested that this could be because students experience difficulties in adjusting to changes in pedagogy from teacher-centred to student-centred learning in science. They also found that more-dominant teacher–student relationships were linked to greater student enjoyment of science but less interest in pursuing science as a career.

Teacher–student cooperation appears to have the strongest influence on attitudes in these studies of students in science and mathematics classrooms. In subjects that involve more practical, hands-on components (such as designing and building prototypes to solve problems in integrated STEM classrooms), student attitudes also could be most-positively influenced by teacher–student cooperation (directing, helping/friendly and understanding) as well as being positively influenced by giving students a greater degree of freedom. For instance, a study of QTI dimensions and attitudes towards work studies in secondary school vocational education revealed that the strongest predictors of positive attitudes and satisfaction with work studies were cooperative teacher–student interactions: directing, helping/friendly and understanding teacher behaviour, together with giving a degree of freedom to students by the teacher (Compliant) (Henderson & Fisher, 2008). However, there have been no studies of the relationship between QTI scales and attitudes towards integrated STEM.

2.3 Attitudes to STEM and gender

In order to understand the declining interest in studying STEM subjects at senior high school and university, attitudes towards individual STEM subjects and gender differences in both attitudes and achievement have been research foci for several decades (Harvey & Stables, 1986; Parker et al., 1996; Reilly et al., 2019). Analyses of data from the 2011 Trends in Mathematics and Science Study (TIMSS) showed no overall differences in mathematics and science achievement between genders globally (Reilly et al., 2019). However, this and other studies also showed that, relative to girls, boys generally have more positive attitudes towards STEM subjects and careers and higher self-efficacy in science and mathematics (Jacobs et al., 2002; Nosek et al., 2002; Riegle-Crumb et al., 2011; Simpkins et al., 2006). Studies of reasons why girls are less positive about STEM subjects and pursuing careers in STEM (e.g. Dicke et al., 2019; Kang et al., 2019; Penner & Willer, 2019) suggest that, together with gender stereotyping of STEM careers as male (Steinke, 2017; Tellhed et al., 2016), girls have lower self-efficacy beliefs and less experience in hands-on activities in engineering, physics and computing (Cheryan et al., 2017).

One factor which positively influences students' attitudes towards learning and self-efficacy beliefs in STEM is social support from peers, teachers and parents (Rice et al., 2013). Socially-supported gender-related beliefs about girls having STEM careers, for instance, have been shown to motivate girls to engage with science/mathematics subjects (Leaper et al., 2012).

Eighth grade appears to be a critical time in the formation of a students' beliefs about their ability in STEM subjects and their intentions to pursue STEM careers (Riegle-Crumb et al., 2011). There are some indications that the introduction of integrated STEM projects into middle schools could improve females' perceptions of STEM subjects and careers (Lou et al., 2011; Roberts et al., 2018) by giving them opportunities to experience hands-on activities and improve their self-efficacy. However, greater understanding is needed of the types of STEM projects, classroom emotional climates and teacher–student interactions that support females' participation in these integrated STEM activities and promote positive attitudes towards STEM.

2.4 Present study

For the purposes of the present study, we focused on social interactions that are malleable by the teacher and described by the four teacher–student interactions in the QTI that vary in their level of dominance but mainly involve cooperation with students (namely, Directing, Helping/friendly, Understanding and Compliant), because these types of interactions have been found to have positive influences on students' attitudes towards individual STEM subjects in the past research reviewed above.

2.5 Hypothesised model

Based on the literature, we hypothesised that classroom emotional climate and each QTI scale (Directing, Helping/Friendly, Understanding and Compliant) would have

direct and positive influences on students' attitudes to STEM. We also hypothesised that each QTI scale would have indirect influences on attitudes to STEM through the mediating influence of teacher–student interactions on classroom emotional climate (Fig. 2).

2.6 Research questions

Using structural equation modelling and based on the model in Fig. 2, model testing and modification were carried out to answer:

Research question 1 Can a modified model, based on an initial theoretical model and with acceptable goodness-of-fit statistics, describe the inter-relationships between classroom emotional climate, four QTI scales and attitudes towards STEM?
Research question 2 Does the same modified model fit data from both males and females and are there gender differences in relationships between latent variables as described by path coefficients?

3 Research methods

3.1 Instruments

Three student questionnaires were administered, namely, a STEM Classroom Emotional Climate (CEC) questionnaire, an Attitudes to STEM questionnaire (Fraser et al., 2021), and a modified and shortened measure probing teacher–student interactions (QTI) (Wubbels & Levy, 1993; Wubbels et al., 2016). The CEC is made up of 41 items assessing seven dimensions of the STEM classroom environment:

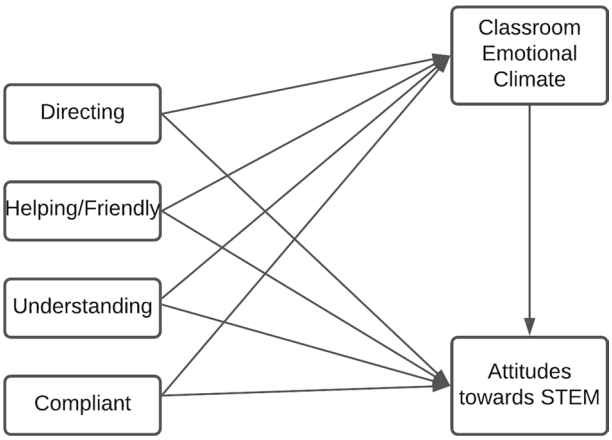

Fig. 2 Theoretical model showing relationships between classroom emotional climate, QTI scales and attitudes towards STEM

Care, Control, Clarity, Challenge, Motivation, Consolidation and Collaboration. A previous validation of the CEC and Attitudes scales confirmed satisfactory internal consistency and concurrent, discriminant and predictive validity, while Rasch analysis of item functioning for each dimension confirmed that these latent variables were unidimensional and had good item fit (Fraser et al., 2021). Principal Component Analysis (PCA) of CEC questionnaire data supported a seven-scale structure, with each item having a factor loading of greater than 0.4 on its own scale and less than 0.4 on all other scales. The total proportion of variance explained by the seven scales was 74.7%. Confirmatory Factor Analysis showed acceptable fit of the theoretical seven-scale model to the data ($\chi 2/df = 2.9$; RMSEA = 0.07; SRMR = 0.05; CFI = 0.94). The structure of the CEC was also shown to be invariant to gender (Fraser et al., 2021). Differential Item Functioning (DIF) carried out to understand whether there was any difference in understanding of items between male and female students showed no significant difference (Koul et al., 2021).

For the 10-item Attitudes to STEM questionnaire, PCA analysis with direct oblimin rotation and Kaiser normalisation revealed good fit with a unidimensional structure rather than a two- dimensional structure, with each item having a factor loading of greater than 0.87 on its scale, and the total proportion of variance explained by the single Attitudes to STEM scale being 84.1%.

Table 1 provides a description of what is measured by and a sample item for each CEC, Attitudes and modified QTI scale are presented in Table 1. Whereas CEC scales assess students' perceptions of aspects of their learning experience within the classroom, the QTI focuses on the students' perceptions of their teacher's teaching style.

3.2 Participants

Students participating in integrated STEM projects at both government and non-government schools in Western Australia were invited to complete the CEC, Attitudes to STEM and modified QTI questionnaires. Responses were obtained from 58 classes in 20 high schools ($N = 698$: male = 294, female = 345, unidentified = 48) where students were completing integrated STEM projects as part of either a Science or Mathematics class or a class involving integrated STEM projects. Most classes were required rather than elective and most integrated STEM projects involved designing solutions to problems and building prototypes and robotics. Student participants attended non-government schools (11 schools, $n = 407$) and government schools (9 schools, $n = 291$) and were in grade 7 (15 classes), grade 8 (9 classes), grade 9 (15 classes), grade 10 (7 classes) and mixed-grade classes (12 classes). After removal of partially-completed responses, complete responses from 624 students remained.

Student data were anonymised and grouped by class code. Ethics approval was obtained from Curtin University and the Education Department of Western Australia and data were only collected from those students whose teachers and parents gave consent and who also gave informed consent.

Participating schools represented a wide range of contexts, including rural district high schools, regional high schools and city-based high schools and K-12 schools.

Table 1 Scale description and sample item for each CEC, Attitudes to STEM and modified QTI scale

Scale	Scale description Extent to which students perceive that…	Sample item (Item number)
CEC care	…their teacher cares about their learning needs and treats them with respect	My teacher makes me feel that s/he really cares about me. (3)
Control	…they behave well in class and remain focused on tasks	I treat the teacher with respect. (4)
Clarity	…their teacher gives clear directions and explanations	My teacher knows when I understand and when I do not. (4)
Challenge	…their teacher encourages them to think deeply and persist in the face of difficulties and provides challenging STEM projects	My teacher asks questions that make me think hard. (1)
Motivation	…their STEM project and the classroom environment motivate them to be engaged in learning and seeking answers to problems	The questions in this class make me want to find out the answers. (2)
Consolidation	…their teacher consolidates understanding, consults with students and indicates how to improve	My teacher asks me questions whether I put up my hand or not. (1)
Collaboration	…they collaborate effectively with peers to complete tasks	I cooperate with other students in my group when doing STEM projects. (1)
Attitudes to STEM	… they are interested in, enjoy and are confident in doing STEM projects and desire to continue studying STEM subjects	I feel confident about doing STEM projects in class. (10)
QTI directing	…the teacher is confident, respected and leads the class well	This teacher is a good leader. (1)
Helping/friendly	…the teacher is dependable and pleasant to be around	This teacher can take a joke. (4)
Understanding	…the teacher listens to students and is helpful, patient and easy-going	This teacher is patient. (1)
Compliant	…the teacher tolerates a variety of student behaviour and is easily influenced by students	This teacher tolerates a lot of student behaviour. (3)

When we checked the Australian Curriculum, Assessment and Reporting Authority's (ACARA) Index of Community Socio-Educational Advantage (ICSEA)—which is based on parents' occupation and education, geographical location and proportion of indigenous students and which ranks schools on a percentage scale (ACARA, 2012)—participating schools were found to range from the 16th to the 97th percentile.

3.3 Data analysis

In a prior validation of the CEC questionnaire, ordinal data derived from student responses to the 41 items assessing seven CEC dimensions were transformed using Winsteps 4.4.7 software (Linacre, 2019) into interval Rasch (1960) measures representing students' responses to each scale (Fraser et al., 2021). These linear Rasch measures were then used as the observed variables for each of the scales that describes the latent variable of classroom emotional climate. Data from the CEC scales (in Rasch logits), Attitudes to STEM items (ordinal data) and QTI items (ordinal data) were analysed using structural equation modelling (SEM) with maximum likelihood estimation using LISREL 10.20 software (Jöreskog & Sörbom, 2018). This allowed investigation of relationships between latent and observed variables in a two-step process (Stevens, 2009). Firstly, the measurement model for each latent variable was estimated to determine the model fit of each observed indicator describing unobserved (latent) variables (Schumacker & Lomax, 2015). Secondly, SEM was used to test structural relationships between latent variables in the proposed theoretical model. We made modifications consistent with the theoretical model and suggested by the LISREL software in order to improve model fit, before conducting further SEM analyses (Schumacker & Lomax, 2015).

Prior to conducting SEM analyses, tests of skewness and kurtosis for each scale were carried out to check that the normality assumption was satisfied. A test of effect size between the proposed model and the modified model was used to compare the two nested models (Schumacker & Lomax, 2015) and achieved power was calculated using G*Power3 software (Faul et al., 2009).

4 Results

Firstly, we answered research question 1 regarding how well the theoretical model fits the data obtained to describe relationships between latent variables.

4.1 Validity of QTI

When the structure of the modified 18-item QTI questionnaire was examined using PCA (Principal Components Analysis) with direct oblimin rotation and Kaiser normalisation, the resultant pattern matrix showed good structural fit for the four dimensions of Directing, Helping/friendly, Understanding and Compliant (Factor Loadings > 0.39). However, one Helping/Friendly item also had a factor

loading of the same magnitude on the Understanding scale. After removing this item and re-running PCA, satisfactory factor loadings, communalities, eigenvalues and percentages of variance were obtained (see Table 2). The total proportion of variance explained by the four QTI scales was 83.2%. Although eigenvalues for the Directing and Helping/Friendly scales were lower than 1.0, factor loadings in the measurement model (presented below) were acceptably high and the model showed good fit.

The alpha reliability coefficient for the four QTI scales ranged from 0.88 to 0.96 (Table 2) and suggests high reliability. Scale item means and standard deviations are given in Table 3. QTI scale means, which can range between 1.00 and 5.00, are higher for student perceptions of the teacher characteristics of Directing, Helping/friendly and Understanding and lower for Compliant. Table 3 also shows that each QTI scale was able to differentiate significantly between the perceptions of students in different classes (i.e., teachers) as evidenced by the results of a one-way ANOVA for each scale with class membership as the main effect and using the individual as the unit of analysis. The eta^2 statistic for each QTI scale, which indicates the amount of variance in student–teacher interaction scores accounted for by the student's class membership, ranged from 21 to 54% for different QTI scales (Table 3).

Table 2 Principal Component Analysis (PCA) results for modified 17-item QTI

Item	Factor loadings				Communalities
	Understanding	Compliant	Directing	Helping/friendly	
Direct 1			0.61		0.88
Direct 2			0.70		0.77
Direct 3			0.79		0.83
Direct 4			0.77		0.84
Friendly 1				0.38	0.83
Friendly 2				0.89	0.88
Friendly 3				0.63	0.77
Friendly 4				0.98	0.91
Under 1	0.79				0.87
Under 2	0.75				0.91
Under 3	0.72				0.87
Under 4	0.82				0.87
Under 5	0.89				0.87
Comp 1		0.88			0.81
Comp 2		0.91			0.83
Comp 3		0.82			0.72
Comp 4		0.80			0.71
%Variance	59.16	16.96	3.99	3.08	
Eigenvalue	10.06	2.88	0.68	0.52	
Cronbach's alpha	0.93	0.93	0.96	0.88	

Table 3 Item mean and standard deviation and ability to distinguish between classes for each QTI scale

Scale	No. of items	Scale item mean	Scale item SD	ANOVA results (eta^2)
Directing	4	4.00	1.10	0.53***
Helping/friendly	4	3.78	1.23	0.52***
Understanding	5	3.94	1.19	0.54***
Compliant	4	2.45	1.14	0.21***

$N = 698$ students in 57 classes, ***$p < 0.001$

Table 4 Skewness and kurtosis of responses to each scale

Scale	Skewness	Kurtosis
CEC	− 0.81	0.13
Attitudes to STEM	− 0.59	− 0.69
Directing	− 1.10	0.30
Helping/friendly	− 0.82	− 0.55
Understanding	− 1.08	0.04
Compliant	0.77	− 0.29

4.2 Skewness and kurtosis

Before carrying out SEM analyses, the skewness and kurtosis of the data were checked for all variables as reported in Table 4. Absolute skewness values were all less than 3 and absolute kurtosis values were less than 10, indicating that the data met the conditions for carrying out SEM on data with a multivariate normal distribution (Kline, 2011).

4.3 Evaluation of structural model

Several different goodness-of-fit indices are commonly used in SEM to determine the fit between a theoretical model (Fig. 2) and the data. Although chi-squared can measure fit, it is highly sensitive to sample size and therefore is more likely to yield a statistically-significant value with our sample. For this reason, other model fit indices are often used, including the ratio of chi-squared/degrees of freedom, with values of 5 or less suggested as acceptable (Hoyle, 2012; Wheaton et al., 1977). Hu and Bentler (1999) recommend use of the root mean square error of approximation (RMSEA) and standardised root mean square residual (SRMR) as absolute measures of fit, with suggested cut-off values of 0.08 or less (Hair et al., 2010). The comparative fit index (CFI) and the Tucker–Lewis index (TLI) are suggested as good measures of incremental fit, with suggested cut-off values of 0.90 or greater (Hair et al., 2010). Gamma hat is considered to be an even more-robust

goodness-of-fit measure than CFI and TLI, with a value of > 0.90 considered acceptable and of > 0.95 considered as good fit (Marsh et al., 2004). Gamma hat = #vars/(#vars + 2 × df × (RMSEA^2) where #vars is the number of manifest or observed variables in a model, df represents the number of degrees of freedom for the model, and RMSEA is the root mean square error of approximation for the model (Fan & Sivo, 2007).

Firstly, we tested the theoretical model in which each QTI latent variable influences both classroom emotional climate and students' attitudes to STEM and classroom emotional climate also influences attitudes (Fig. 2, Model 1). LISREL suggested the addition of a number of correlations between error covariances in order to reduce the chi-squared value and improve model fit. Correlations between error covariances were added between items belonging to the same scales before the SEM was re-evaluated (Schumacker & Lomax, 2015). Fit statistics obtained for SEM (Model 1) are presented in Table 5 for the whole sample. While there were satisfactory incremental fit values for CFI and TLI, values for RMSEA and χ^2/df were slightly higher than desired.

Standardised path coefficients for Model 1 are presented in Table 6 and Fig. 3 for the whole sample. Coefficients for all paths were statistically significant at the 0.05 level except the path between Friendly and CEC. Additionally, path coefficients between Compliant and CEC and between Compliant and attitudes were extremely small, although statistically significant, suggesting that the Compliant scale could be removed with little effect on the overall model.

In Model 2, the Compliant scale and the nonsignificant path between Friendly and CEC were removed (Fig. 4). All correlations between error covariances remained unchanged. Fit statistics in Table 5 for Model 2 for the whole sample show that values for CFI, TLI, SRMR, RMSEA and χ^2/df were all acceptable and within ranges recommended in the literature. Although gamma hat still was not above 0.9 for model 1, it was higher than for Model 1.

Standardised path coefficients for each of the hypothesised relationships in Models 1 and 2 for the whole sample are summarised in Table 6. For Model 2, there were direct positive relationships between Directing and Understanding teacher–student interactions and classroom emotional climate and an indirect relationship to Attitudes to STEM. However, Directing and Understanding teacher–student interactions had negative direct relationships with students' Attitudes towards STEM. Helping/friendly teacher–student interactions had little or no effect on CEC, but had a strong,

Table 5 Fit statistics from SEM for Model 1 (for whole sample) and Model 2 (for whole sample, males only, and females only)

Model and sample	χ^2/df	CFI	TLI	Gamma hat	SRMR	RMSEA (90% confidence interval)
Model 1, whole sample	5.14	0.94	0.93	0.85	0.044	0.081 (0.078–0.085)
Model 2, whole sample	4.57	0.96	0.95	0.88	0.033	0.076 (0.072–0.079)
Model 2, females only	5.19	0.91	0.90	0.77	0.038	0.112 (0.107–0.117)
Model 2, males only	5.57	0.89	0.87	0.72	0.039	0.129 (0.123–0.135)

Table 6 Standardised path coefficients for hypothesised relationships for model 1 (for whole sample) and Model 2 (for whole sample, males only and females only)

Hypothesised relationship	Standardised path coefficient			
	Model 1	Model 2	Model 2 female	Model 2 male
Directing CEC	0.48***	0.55***	0.72***	0.46***
Helping/Friendly CEC	0.10			
Understanding CEC	0.38***	0.40***	0.24*	0.49***
Compliant CEC	− 0.02**			
Directing Attitudes to STEM	− 0.31**	− 0.35**	− 0.78*	− 0.26
Helping/Friendly Attitudes to STEM	0.66***	0.70***	0.95*	0.57***
Understanding Attitudes to STEM	− 0.58***	− 0.61***	− 0.55***	− 0.66***
Compliant Attitudes to STEM	0.04***			
CEC Attitudes to STEM	0.98***	1.01***	1.06***	1.19***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

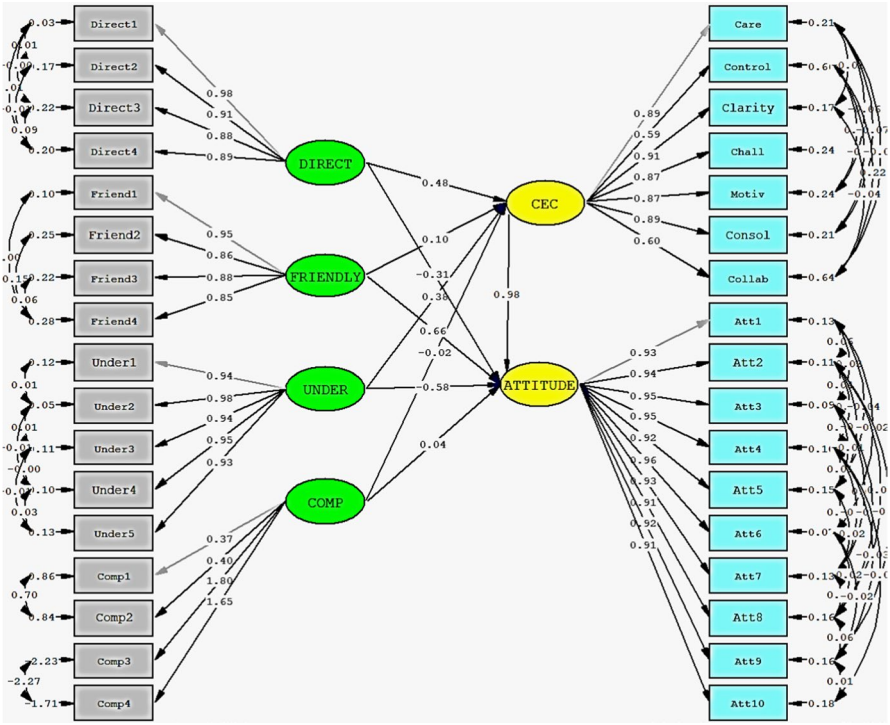

Fig. 3 Model 1 showing standardised path coefficients for measurement model and SEM

direct and positive influence on Attitudes to STEM. Overall, CEC had a strong positive relationship with students' Attitude to STEM for the whole sample.

In response to Research question 2 regarding whether relationships between variables differ for males and females, SEM was conducted for Model 2 separately for males only and for females only. Fit statistics of the male only and female only sets showed acceptable values for CFI, TLI and SRMR. RMSEA and χ^2/df values were higher than is recommended and gamma hat values were lower than desired, possibly due to smaller sample sizes. The standardised path coefficients for Model 2 in Table 6 show that the positive relationship between Directing teacher–student interactions and CEC was much stronger for females than for males, while the relationship between Understanding teacher–student interactions and CEC was stronger for males than for females. Directing teacher–student interactions had a nonsignificant relationship with males' Attitudes, but a strong negative association with females' Attitudes. Helping/friendly teacher–student interactions had a stronger positive effect on Attitudes towards STEM for females than males, whereas Understanding teacher–student interactions had a negative influence on both male and female students' attitudes towards STEM (Table 6).

The coefficient of determination for the endogenous latent variables in Model 2 indicates that 87% of the variance in classroom emotional climate was accounted for by teacher–student interactions which are Directing, Helping/friendly and Understanding

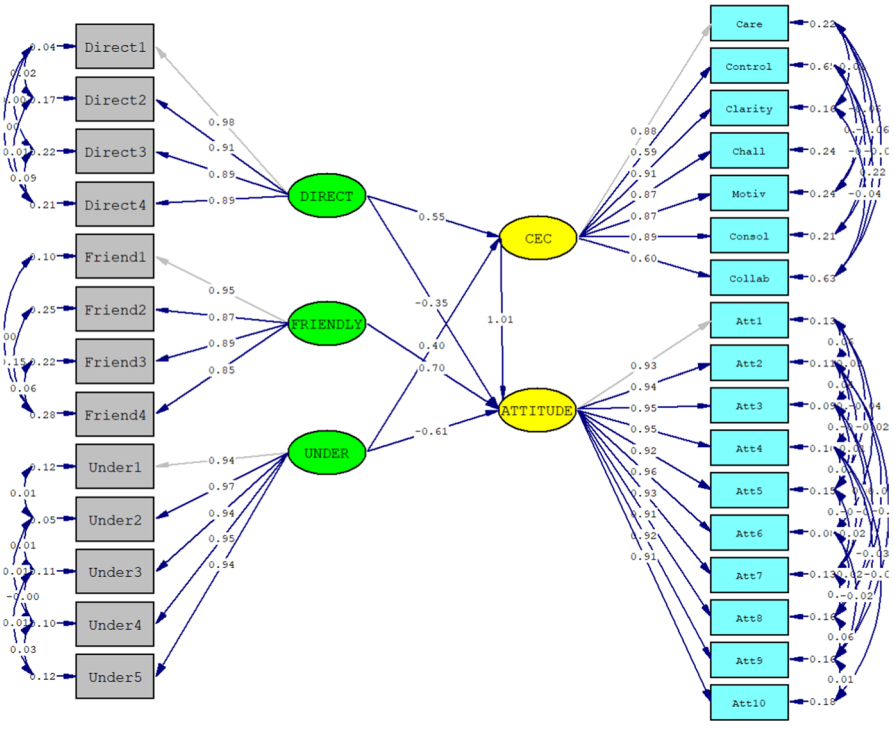

Fig. 4 SEM Model 2 showing standardised path coefficients for measurement and SEM models

(Table 7). Likewise, 63% of the variance in students' Attitude to STEM was determined by classroom emotional climate and Helping/friendly and Understanding teacher–student interactions (Table 7).

Direct, indirect and total effects of classroom emotional climate, Directing, Helping/friendly and Understanding teacher–student interactions for Attitudes to STEM for Model 2 are presented separately for males and females in Table 8. While the direct effect of directing teacher-student interactions on females' attitudes to STEM was negative, this was cancelled out by the indirect effect mediated by CEC. For males, however, although the direct effect of directing teacher-student interactions on attitudes to STEM was negative, it was smaller and not significant compared to the effect for females and the total effect was positive. Similarly, a negative direct effect on attitudes of an understanding teacher-student interaction for females was somewhat reduced by a positive indirect effect mediated by CEC, although the overall effect remained negative. For males the indirect effect on attitudes to STEM of having an understanding teacher, mediated by CEC, almost cancelled out the direct effect.

Finally, an effect size comparing Models 1 and 2 was calculated using Schumacker and Lomax's (2015) method for nested models when the between-model degrees of freedom are greater than or equal to 1. The effect size was estimated to be 1.07 for the whole sample. Conducting a G*Power3 post hoc analysis revealed that achieved power was 1.00 at $\alpha = 0.05$, indicating that differences between RMSEA values for Models 1 and 2 were statistically significant.

5 Discussion

This study clarified relationships between teacher–student interactions, classroom emotional climate and students' attitudes towards STEM, including intentions to continue in the STEM pipeline. These findings provide a basis for further research into classroom factors within integrated STEM classrooms that could support students in developing positive attitudes towards STEM careers. Past research shows that, from grade 8 onwards, students are consolidating their beliefs and intentions related to choosing subjects and careers in STEM (Kennedy et al., 2020; Riegle-Crumb et al., 2011). Our study suggests that positive attitudes to STEM are facilitated by a careful balance between clear directions and classroom organisation led by the teacher, as well as cooperation with students as they undertake their STEM projects.

Based on prior research suggesting that that teacher–student interactions emphasising dominance and cooperation positively influence students' attitudes in science and mathematics classrooms, we anticipated that teacher profiles that were directing, helping/friendly or understanding would each have a positive influence on students'

Table 7 Coefficient of determination (R^2) for the endogenous constructs for Model 2

Endogenous construct	R^2
Classroom Emotional Climate (CEC)	0.867
Attitudes to STEM	0.629

Table 8 Standardised direct, indirect and total effects of QTI and CEC scales on Attitudes to STEM

Variable	All students' attitudes			Females' attitudes			Males' attitudes		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
Directing	− 0.35**	0.56***	0.21***	− 0.78*	0.76***	− 0.02*	− 0.26	0.55***	0.29**
Helping/friendly	0.70***	–	0.70***	0.95*	–	0.95*	0.57***	–	0.57***
Understanding	− 0.61***	0.40***	− 0.21***	− 0.55***	0.25*	− 0.30*	− 0.66***	0.58***	− 0.08***
CEC	1.01***	–	–	1.06***	–	1.06***	1.19***	–	1.19***

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

attitudes towards integrated STEM classes and continuing in the STEM pipeline (den Brok et al., 2004; den Brok et al., 2005; Fisher et al., 1995, 2005; Telli et al., 2010). In addition, the practical nature of many STEM projects suggests that compliant teachers, who allow students to make their own decisions and run their own projects with little influence, would help students to develop skills in independent problem solving and positive feelings about STEM (Henderson & Fisher, 2008). However, our SEM analyses showed that, although compliant teacher–student relationships were significantly related to both attitudes to STEM and classroom emotional climate, the very small magnitudes of standardised path coefficients suggest little or no impact.

SEM revealed that, while a combination of directing and understanding teacher–student interactions had a positive influence on students' perceptions of the classroom emotional climate, surprisingly, these profiles had a negative association with students' attitudes towards STEM (Table 6). On the other hand, while a positive classroom emotional climate had a direct positive association with attitudes, the most-powerful indicator of positive STEM attitudes in terms of teacher–student interactions was a helping/friendly approach by teachers. Apparently, there is a very fine line between giving too much freedom to students while they carry out their STEM projects and dominating students' choices. Students seem to respond more positively when the teacher provides some direction and they feel that they are consulted and can work together with the teacher in a pleasant atmosphere of collaboration. In particular, girls favoured this kind of approach from their teachers when carrying out STEM projects (Table 6). Girls, however, had a strongly negative response to dominating teacher profiles in terms of their attitudes towards STEM, while boys were significantly influenced neither positively nor negatively by a dominant teacher profile. This could be related to lower self-efficacy beliefs and less experience in hands-on activities in engineering, physics and computing reported amongst girls compared to boys (Cheryan et al., 2017). A teacher who is highly directive with students, allowing them little freedom to experiment or solve problems themselves, actually could reinforce these low self-efficacy beliefs among students, particularly girls, by making them doubt their ability to complete these tasks independently. However, a classroom environment where anything goes appears to also be counterproductive. Despite the direct negative influence of a directing or understanding approach to teaching on attitudes to STEM, both of these profiles had an indirect and positive association with attitudes, mediated through a more-positive classroom emotional climate. Apparently, students feel more comfortable when the teacher directs their actions in integrated STEM classrooms. Students also appreciate having their ideas and needs listened to by an understanding teacher. However, in the longer term, teachers being too directing or understanding actually could lead to a decrease students' beliefs in their capacity to pursue STEM subjects. This evidence supports the need for a student-centred approach to teaching within integrated STEM classrooms, while providing sufficient scaffolding to guide students in problem solving.

5.1 Limitations and future directions

Our sample was one of convenience because obtaining consent from both parents and students limited participation in the study to students who were motivated

enough to complete the necessary forms. Although the data set was moderately large, the relatively small size of the male and female subsamples led to less-than-ideal model fit statistics for these groups. Ideally, a larger future sample (for greater statistical power) and a more-representative sample (for better generalizability) would be desirable. Nevertheless, the variety of school settings from 58 classes in rural and urban Western Australia suggests that our data probably were representative of students participating in integrated STEM projects.

We used only four of the QTI's eight QTI scales in order to reduce the time needed for students to respond to all questionnaires, including our 41-item measure of classroom emotional climate. In future research, we recommend inclusion of all eight QTI scales, together with the seven classroom emotional climate scales and the attitudes scale, to obtain a more complete-understanding of the effect of teacher–student interactions and classroom emotional climate on attitudes to STEM.

Use of the CEC questionnaire in combination with the QTI and attitudes to STEM scale provided a window into students' experiences within the integrated STEM classroom. This research could be extended in order to further understand preferred teacher–student interactions within the STEM classroom, particularly for girls. What aspects of helping/friendly teacher–student relationships particularly support girls in developing positive attitudes towards STEM? Are the same interactions found for students at all grade levels?

Additionally, in past studies of social support from peers and family, peer and family attitudes and encouragement significantly influenced students' self-efficacy beliefs and hence their attitudes towards science/mathematics and presumably to STEM-related careers (Rice et al., 2013). A study of girls' motivation in science/mathematics subjects showed that parental and peer support for engagement with these subjects increased the expectancy value given to these subjects (Leaper, 2015; Leaper et al., 2012). In a large-scale secondary analysis of data from 7000 students, the classroom, home and peer environments each explained a statistically-significant amount of unique variance in science/mathematics students' attitudes (Fraser & Kahle, 2007). However, because our study focused on factors within the integrated STEM class which potentially are malleable by teachers, including peer and family support was beyond the remit of this research. However, the model that we propose could be further elaborated through probing students' perceptions of peer and family support in future studies.

6 Conclusion

Our study suggests that different teacher–student interactions are needed within integrated STEM classrooms than in science or mathematics classrooms. The less-structured and more open-ended nature of integrated STEM problems (Nadelson & Seifert, 2017) could require a balance between giving enough direction and support for students to develop skills and understand the task, while authentically cooperating with students in setting goals. Care should be taken to provide enough direction within the classroom to ensure a positive classroom emotional climate in which students perceive that teachers care about their needs, listen to their concerns, give

clear instructions and feedback, and provide large- and small-group settings that are monitored enough to enable productive work (Fraser et al., 2021). At the same time, student initiative should be supported and encouraged in an environment that is neither too restrictive nor too laissez faire.

Author contributions FM collected and analysed the data and made a major contribution to writing the manuscript. BF designed the project and made a major contribution to writing the manuscript. RK designed the project. BF and RK were recipients of the grant.

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Data availability The datasets generated and analysed during the current study are not publicly available due to ethics requirements for anonymity but are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors have no conflicts of interest to declare that are relevant to the content of this article.

Ethical approval This research involved Human Participants and Ethics Approval was obtained from Curtin University Ethics Committee before data was collected.

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