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Systemizing and the gender gap: examining academic achievement and perseverance in STEM

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Abstract For years, a popular explanation for women choosing to abandon studies in science, technology, engineering, and mathematics (STEM) has been their lack of aptitude. This study challenged that notion by integrating theories of cognitive style, academic emotion, self-efficacy, and motivation to explain students' academic achievement and perseverance in STEM when transitioning to college. A sample of 1597 high school and junior college students participated. Exploratory and confirmatory factor analyses were first conducted to validate a reduced version of the cognitive style questionnaire. Structural equation modeling revealed that the cognitive style known as systemizing indirectly predicted STEM achievement and persistence by way of intrinsic motivation, learning anxiety, and self-efficacy, providing a new perspective for re-examining the gender gap in STEM.

Keywords Gender gap · STEM · Cognitive style · Self-efficacy · Intrinsic motivation

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Introduction

Gender-based discrepancies in science, technology, engineering, and mathematics (STEM) participation vary by domain, country, and culture, but one consistent finding is that males are more likely than females to pursue college majors and careers in math-intensive STEM domains (Mann et al. 2015; Su and Rounds 2015); yet, contemporary meta-analyses reveal gender parity in mathematics performance and aptitude (Lindberg et al. 2010). The primary goal of the present study was to formulate a model that could explain adolescents' intentions to pursue STEM programs in college. A secondary objective was to determine if our model could account for the well-publicized gender gap in STEM at the undergraduate level.

Our model consisted of a novel integration of concepts from four theoretical perspectives: empathizing–systemizing (E–S) theory (Baron-Cohen 2003), the control–value theory of achievement emotions (Pekrun et al. 2002), self-determination theory (SDT; Ryan and Deci, 2000), and social cognitive theory (Bandura 1997). Prior research has demonstrated that each of these theories provides distinct explanations for achievement and perseverance, yet to the best of our knowledge, they have yet to be integrated to formulate a testable model of academic persistence. Specifically, we examined the hypothesized effects of cognitive style, intrinsic motivation, anxiety, and self-efficacy on academic achievement in STEM in high school and junior college and on intentions to persist in STEM programs in college. Prior to testing the model, exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted to validate the reduced Systemizing Quotient (SQ; Baron-Cohen et al. 2003) scale used to measure cognitive style. The results of the best-fitting model are then presented and discussed, followed by practical implications for STEM enrollment and persistence in higher education.

E–S theory

E–S theory (Baron-Cohen 2003) is built upon the notion that the human brain has evolved to sustain our species by adapting to an ever-changing environment that contains two different components: the physical world, governed by what we might term mechanical laws, and the social world. E–S theory hypothesizes that the evolutionary process of adaptation to these two distinct environments led to the development of two different cognitive styles.[1] The systemizing cognitive style is defined as the drive to analyze rule-based systems in the physical environment and to make predictions about the behavior of those systems (Baron-Cohen 2003). Conversely, the empathizing cognitive style refers to the drive to identify the mental states of people, to make predictions about the future behavior of those people, and to generate appropriate emotional responses (Baron-Cohen et al. 2003; Wheelwright et al. 2006). Although individuals utilize both styles in their day-to-day functioning, they are unlikely to be equally proficient in both.

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[1] Cognitive style is a concept that describes the way people prefer to think, perceive, and remember information (see Kozhevnikov et al. 2014). Various authors have defined this concept differently. Riding and Cheema (1991) reviewed many theories of cognitive style and discovered that some theories focus on preferences for organization and structure, for example, Watkins, 1972) of preference for external (field dependent) or internal structure (field independent). Other theories may focus on modes of information representation in memory (e.g., Paivio's (1971) dual coding theory). In order to avoid confusion, we will carefully describe the definition of cognitive style in the context of this paper.

E–S theory suggests that there are partly biologically determined sex differences in cognitive style such that males are likely, on average, to be higher in systemizing than females, and females are likely to be higher in empathizing. To test the distribution of cognitive styles among clinical and nonclinical populations, structured self-report questionnaires were designed to measure the extent to which individuals are inclined to systemizing and empathizing (Baron-Cohen et al. 2003). The measure of an individual's systemizing style is referred to as the SQ, whereas their empathizing style is operationalized as the empathy quotient (EQ). Research utilizing these measures has shown that, on average, males tend to have higher scores on systemizing compared to females, while females tend to score higher on empathizing relative to males (Nettle 2007; Wright and Skagerberg 2012). This finding is largely stable across Western cultures (Baron-Cohen et al. 2014; Wright and Skagerberg 2012), but less consistent with Eastern cultures (Wakabayashi, et al. 2007; Zheng and Zheng 2015).

Given the gender differences, researchers have utilized E–S theory to examine gender disparities in multiple domains (Nettle 2007; Svedholm-Häkkinen and Lindeman 2015). Concerning domain and program selection in education, research has revealed that students pursuing degrees in math-intensive STEM programs were higher in systemizing and lower in empathizing relative to their counterparts in the humanities (Wakabayashi et al. 2012; Wheelwright et al. 2006). Recently, it was found that, on average, students in the physical sciences had a stronger drive to systemize than to empathize, irrespective of their gender, while the reverse was found for students in the humanities (Kidron, et al. 2018). Importantly, cognitive style was superior to gender in predicting program enrolment; thus, domains that require proficiency in systemizing skills, such as mathematical and spatial competences (Baron-Cohen 2003, 2008), typically attract individuals with a higher systemizing–lower empathizing cognitive profile.

Given the partly biological origins of E–S theory and its potential implications, the systemizing–empathizing perspective is not without its critics (Nash and Grossi 2007; Spelke 2005); however, related perspectives have obtained comparable results when attempting to account for STEM gender disparities. For example, women's under- and over-representation in specific domains may be the result of underlying differences in interests or orientations towards people versus things. Females are more oriented towards majors and careers that focus on people, whereas males tend to be oriented towards things (Su and Rounds 2015; Su et al. 2009). Importantly, orientations and interests predict STEM majors and careers.

In education, research on individual differences in cognitive styles has largely focused on whether instructional modes may improve achievement (Hirnstein et al. 2009; Riding and Rayner 2013); however, there is limited research testing the assumptions of E–S theory as they pertain to educational and occupational choices in adolescence and beyond. The present study examined systemizing as a predictor of achievement and perseverance in STEM domains among adolescents. We hypothesized that male students would be higher in systemizing than females and that the cognitive style would positively predict the intention to pursue STEM majors in college. Additionally, we expected that there would be several important psychological and affective variables that mediated the systemizing–persistence relation.

Self-determination theory

SDT is a theory on human motivation (Deci and Ryan 2017) that distinguishes between different amounts and types of motivation. The most basic distinction is between intrinsic motivation (i.e., taking an action because of inherent interest or pleasure) and extrinsic

motivation (i.e., taking an action because of foreseeable separable consequences). SDT further postulates that intrinsic motivation flows from innate human psychological needs for competence, autonomy, and relatedness. When learning tasks or the learning setting is designed to meet these needs, intrinsic motivation is expected to rise and learning outcomes are expected to improve.

Extrinsic motivation is divided into four hierarchical states: external regulation, where motivation is a response to either extrinsic rewards or threats of punishment; introjected regulation, which involves the learner's ego and the potential approval of others; identified regulation, which involves a conscious valuing of the activity and a self-endorsement of goals; and integrated regulation, which involves a synthesis of goals into a congruent whole. SDT theorists suggest that these types of extrinsic motivation lie along a continuum of degree of autonomy. External regulation is a completely controlled form of regulation, and the degree of autonomy grows from introjected regulation to integrated regulation, with the latter being completely autonomous.

Numerous studies have shown that intrinsic motivation leads to the expression of more creativity, stronger academic self-concepts, higher academic performance, and involvement in meaningful cognitive engagement (Clark et al. 2014; Guay and Vallerand 1997; Ratelle et al. 2007). There is also evidence that more autonomous forms of regulation result in more positive learning experiences and higher achievement, for example, in science (Taylor et al. 2014), psychology (Burton et al. 2006), and French, mathematics, geography, and history (Guay and Vallerand 1997). In contrast, external regulation, introjected regulation, and amotivation have been shown to result in negative outcomes such as poor school adjustment (Walls and Little 2005) and dropout (Vallerand, Fortier, and Guay 1997).

E–S theory is also a theory of motivation in that it differentiates the "drive" to systemize and the "drive" to empathize. It implies that systemizers will be motivated to study subjects like science, and empathizers will be motivated to pursue people-centered fields. Indeed, previous studies (Zeyer et al. 2013; Zeyer et al. 2012) found significant positive correlations between systemizing and motivation to learn science as measured by the Science Motivation Questionnaire (SMQ; Glynn and Koballa 2006), which includes intrinsic and extrinsic items. It is probable that low systemizers will not enjoy studying science. Instead, their motivation is likely to be externally regulated and controlled, which is related to showing less interest, effort, and persistence. In contrast, it is likely that high systemizers will enjoy studying science and hence have higher intrinsic motivation, which has been associated with more academic interest, greater achievement striving, and positive coping styles (Ryan and Deci 2017). However, what is lacking is a clear understanding of the relation between systemizing cognitive style and motivation to study science when sub-domains of science are assessed. We hypothesized that students who are higher in systemizing would have greater intrinsic motivation in math-intensive STEM domains.

Self-efficacy

In social cognitive theory (Bandura 1986), people are self-organizing, proactive, and self-regulating, rather than reactive and governed by external events. Perceived self-efficacy functions as an essential factor that influences self-regulatory mechanisms (Bandura and Wood 1989). Self-efficacy is defined as "the belief in one's capabilities to organize and execute courses of action required to produce desired attainments" (Bandura 1986, p. 391). Self-efficacy beliefs affect individuals' choices of activities, effort, and maintenance of

behavior. It is what people *believe* they can accomplish with the abilities they possess that is important rather than their actual abilities (Bong and Skaalvik 2003).

In the academic context, students' beliefs about their ability to successfully complete academic tasks (i.e., academic self-efficacy) are strong predictors of their actual ability to achieve such outcomes (Bandura 1997; Skaalvik and Skaalvik 2008). In many fields, students' domain-specific self-efficacy perceptions influence their motivation and academic accomplishments. Moreover, students' mastery experiences (i.e., how an individual interprets performance) within a domain influence their self-efficacy beliefs (Bandura 1997). High systemizers are likely to enjoy thinking in terms of experiments with objects and working with numbers, which helps them acquire mastery experiences and increase their self-efficacy in areas that involve working with numbers and inanimate systems. In contrast, low systemizers are likely more discouraged by situations where they have to analyze systems or mathematical problems and may experience fewer mastery experiences and lower self-efficacy in such areas.

Physiological and emotional states such as anxiety and stress are another source believed to influence self-efficacy beliefs (Bandura 1997). For example, an individual who experiences optimal levels of stress and anxiety when analyzing systems and solving mathematical problems is expected to develop greater self-efficacy for these activities. Alternatively, someone who experiences maladaptive levels of stress and anxiety in such situations is expected to cognitively appraise this information in a manner that would lower their self-efficacy for these activities. Thus, a low systemizer might well be expected to have lower self-efficacy and be more anxious when confronted with a systemizing problem to solve. Therefore, we believe that it is important to study self-efficacy beliefs and academic emotions in conjunction with cognitive style.

Mathematics anxiety

Research has shown that students frequently experience a variety of emotions in learning and achievement contexts (Efklides and Volet 2005; Pekrun et al. 2002; Pekrun and Linnenbrink-Garcia 2012). Thus far, mathematics anxiety has received substantial empirical attention, and it has been found to have negative effects on student persistence and achievement in math-intensive domains (Ashcraft 2002; Ma 1999). Several studies have shown that girls often are more anxious than boys in contexts that involve mathematical reasoning and that domain-specific anxiety has an important influence on the development of gender differences in math performance (Devine et al. 2012; Goetz et al. 2013). Previous studies have also found relations between mathematics anxiety and mathematics self-efficacy (Hoffman 2010; McMullan et al. 2012). Moreover, the control–value theory of achievement emotions (Pekrun 2006) suggests that self-efficacy can mediate the impact of mathematics anxiety on achievement, which has been confirmed in several studies (Pekrun 2006).
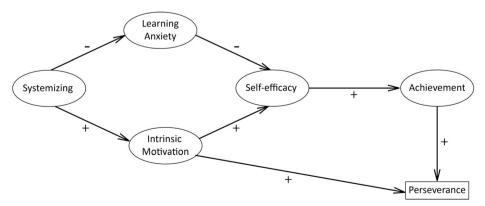
The present study

We hypothesized that systemizing cognitive style would indirectly predict STEM achievement and intention to persist by way of intrinsic motivation, mathematics anxiety, and STEM self-efficacy. For example, higher systemizing was expected to relate to higher intrinsic motivation and self-efficacy and lower anxiety in math-intensive STEM domains, which in turn were expected to relate to higher achievement in pre-college STEM courses and stronger intentions to persist in STEM in college. There are few empirical studies linking systemizing cognitive

skills with learning anxiety or intrinsic motivation (Zeyer et al. 2013), but Halpern and LaMay (2000) argue that individuals acquire cognitive systemizing skills by spontaneously engaging in activities in which those skills are useful. These experiences lead to decreased anxiety in novel situations and increased motivation to further engage in such tasks. Thus, we hypothesized that systemizing would be positively related to intrinsic motivation and negatively related to anxiety.
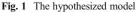
On the other hand, there is ample empirical evidence suggesting that negative emotions are associated with decreased self-efficacy (Akin and Kurbanoglu 2011; Nie et al. 2011) and that intrinsic motivation is positively related to self-efficacy (Bryan et al. 2011; Glynn et al. 2011). Thus, building on our hypotheses regarding systemizing cognitive style, we further expected learning anxiety to negatively predict self-efficacy and intrinsic motivation to positively predict self-efficacy. Additionally, self-efficacy beliefs concerning the ability to succeed at tasks in science and mathematics courses were expected to directly and positively relate to achievement (Bandura et al. 2001; Bryan et al. 2011). We also hypothesized that intrinsic motivation and achievement would be positively related to perseverance (Hardre and Reeve 2003; Lavigne et al. 2007). These hypothesized associations culminated in the model shown in Fig. 1.

Methodology

Participants

Participants consisted of a non-random selection of students enrolled in four junior colleges in Quebec, Canada, and eight metropolitan high schools from three provinces in Sweden. All participants were on an academic trajectory towards STEM studies in college by being enrolled in a science program in their final year of high school (Swedish participants) or their first year of a two-year junior college program (Canadian participants). An initial questionnaire was administered to 1625 students (74% Canadian; 26% Swedish) during mathematics/science classes in the second week of the fall semester of the Swedish participants' final year in high school and the Canadian participants' second week of the fall semester in the first year in junior college. Prior to graduating from high school or junior college, and having already submitted their college entrance applications, participants were sent a second, brief questionnaire to assess their intention to enroll in a STEM program in college. Participants were compensated by entry into a lottery were they could win movie tickets.

Fig. 1 The hypothesized model

To minimize the impact of missing data, the sample was partitioned into two parts: a model-validation sample consisting of students with complete achievement and perseverance data and a scale-validation sample consisting of the remaining students. There were 1057 participants (497 females) in the model-validation sample and 540 participants (261 females) in the scale-validation sample. The age ranged from 18 to 19 years old including 277 Swedish students (132 females) in the model-validation sample and 140 Swedish students (64 females) in the scale-validation sample. Twenty-eight univariate outliers ($|z| > 3$) were identified and removed from further analyses.

Instruments

Systemizing

An instrument assessing systemizing cognitive style was adapted from the SQ (Baron-Cohen et al. 2003). The original systemizing scale has 75 items, which is prohibitively long and difficult to administer in a classroom without causing major interruptions. In addition, many of the items in the original scale make specific reference to a British context, which would be meaningless to students/people from other countries. Our initial process was to eliminate all redundant items and items not compatible in a Canadian and Swedish context. This was done by investigating the meaning, criterion validity, and face validity of each item. Four independent respondents, teachers in mathematics and physics, examined each of the original items to determine whether they were easy to understand and appropriate in a Canadian and Swedish context. In this process, we reduced the original scale to 20 items that were not redundant, not difficult to understand, but highly relevant to the context of the study. After this process, 20 items remained. In the next step of the adaptation process, statistical techniques were used to refine the instruments even more by means of exploratory factor analyses and reliability tests.[2] Based on the consistency results, eight items showed acceptable reliability ($\alpha = 0.71$; see Appendix). Responses were rated on a four-point Likert scale ranging from strongly disagree to strongly agree. Both EFA and CFA were conducted to examine the internal structure of this scale.

Self-efficacy

Self-efficacy in mathematics and sciences was measured using a five-item scale adapted from the Motivated Strategies for Learning Questionnaire (MSLQ; Pintrich et al. 1991). The items refer to students' beliefs concerning their competence to perform typical tasks in STEM. Responses were rated on a four-point Likert scale ranging from *strongly disagree* to *strongly agree*). The reliability for this scale in the current study was acceptable ($\alpha = 0.81$).

Learning anxiety

A four-item scale adapted from the Achievement Emotions Questionnaire (AEQ; Pekrun et al. 2002) was used to assess anxiety experienced by students when studying physics. Responses were rated on a four-point Likert scale ranging from *disagree* to *agree*. The reliability for this scale in the current study was acceptable ($\alpha = 0.79$).

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[2] This process was implemented in an earlier, unpublished research effort and is based on a different sample of Canadian STEM students.

Intrinsic motivation

A four-item subscale measuring intrinsic motivation was adapted from the Academic Motivation Scale (AMS; Vallerand and Bissonnette 1992). Responses were rated on a four-point Likert scale ranging from *strongly disagree* to *strongly agree*. The reliability for this scale in the current study was acceptable ($\alpha = 0.89$).

Academic achievement

Student grades in physics, chemistry, and mathematics courses were obtained from the Ministry of Education of Quebec and the administrative offices of the Swedish high schools; however, as participants were drawn from two different school systems, course content and grading systems needed to be reconciled. Subject experts on our team studied the curriculum of the advanced courses in Swedish high school and Quebec junior college and concluded that the two advanced Swedish courses in mathematics were equivalent to the junior college calculus course. Furthermore, the advanced courses in chemistry and in Swedish high school were determined to be equivalent to the general chemistry and mechanics courses in Quebec junior college. Thus, for Canadian participants, academic achievement consisted of their final grades in chemistry, mechanics, and calculus courses from their first semester in college. For Swedish participants, final grades in mathematics, physics, and chemistry courses taken in the final year of high school were the observed indicators of achievement.

The scale used in the course grades in Canada ranged from 0 to 100%, and, in Sweden, the scale used in the course grades ranged from Fail = 1, Pass = 2, Pass with distinction = 3, and Pass with great distinction = 4. Fail in the Swedish system corresponded to a grade of 0–49% in the Canadian system. Pass in the Swedish system corresponded to a grade between 50 and 69% in the Canadian system. Pass with distinction in the Swedish system corresponded to a grade of 70–89% in the Canadian system. Pass with great distinction in the Swedish system corresponded to a grade of 90–100% in the Canadian system. In both countries, the final grade was determined by an overall performance grade based on a variety of assessments, such as the grades on the examinations in each relevant subject. Grades in the two samples were converted to standardized z-scores, which allowed for comparison between the two subsamples.

Intention to persist (perseverance)

To assess intention to persist in STEM, participants were asked the following question: *What is the likelihood that you will continue to study in a science/engineering program at a university within the next two years?* The responses were measured on a four-point Likert scale ranging from *very unlikely* to *very likely*. The data were collected after students had completed their college applications, which was approximately two months before the end of the spring semester in students' final year before college.

Data analysis

EFA and CFA were used to examine the structure of the systemizing scale and to assess its internal consistency. The scale-validation sample was randomly divided into exploratory ($n = 265$) and confirmatory ($n = 275$) samples while maintaining an equivalent proportion of females and males as well as Swedish and Canadian students. Multivariate outliers (i.e., cases

with Mahalanobis distance exceeding the critical value) were identified and removed prior to the analysis. EFA was carried out using a maximum likelihood (ML) algorithm and direct oblimin rotation. Goodness-of-fit and scree tests were used to select a parsimonious model. Significance values for the EFA chi-square tests were $p < 0.001$. CFA was carried out using the EQS program (Bentler 1995) to confirm the selected model. Based on the results of the CFA, remaining items were combined into internally consistent indicators of systemizing (Little et al., 2002). The authors of the scales for learning anxiety, intrinsic motivation, and self-efficacy established unidimensionality. Thus, only CFA was carried out with the confirmatory sample for these scales, and the results were used to combine items into balanced indicators of each construct (Little et al. 2002). Such parceling techniques have been recommended as a way of obtaining more normally distributed indicators for use in structural equation modeling (SEM) to produce better model fit in empirical studies (see, e.g., Landis et al., 2000).

In the second stage of analysis, SEM (EQS; Bentler 1995), based on the analysis of covariance matrix, was utilized to examine the hypothetical causal model, which postulated that the constructs (latent factors) of systemizing, learning anxiety, intrinsic motivation, and self-efficacy are causally related to two outcomes: perseverance and achievement (latent factor). Using an approach recommended by Byrne (2006), the analysis was carried out in three steps (multivariate outliers were examined at each step). In step 1, CFA was carried out to examine the structure of instruments involving indicators as observed variables for each gender and to test for invariance of factor loadings. To execute this step, the model-validation sample was divided into two subsamples—females and males.

In step 2, the model-validation sample was randomly split into calibration (female $n = 245$; male $n = 276$) and validation (female $n = 245$; male $n = 275$) samples while maintaining equal proportions of Swedish and Canadian participants. The hypothetical model was tested separately for each gender using the calibration samples. The Lagrangian multiplier test (LM test) for adding parameters that may improve model fit and the Wald test (W test) for identifying parameters that are not significant were employed. When the best-fitting model was established for each gender, the model was tested for invariance of all causal paths across the validation sample for each gender.

Finally, the model was tested for invariance of all common causal paths across genders. In anticipation of the possibility that variables might not be normally distributed, ML and Robust methods were used simultaneously during each iteration. When the elevated Mardia coefficient indicated high multivariate kurtosis, results of the Robust method are reported. Three statistics of model fit were used: the Satorra Bentler Scaled Statistics (S-BSS) divided by the number of degrees of freedom (S-BSS/df), the comparative fit index (CFI), and the root mean-square error of approximation (RMSEA) with a 90% confidence interval. Bentler (1995) recommends an acceptable best-fitting model should have a S-BSS/df < 3, a CFI > 0.90, and a RMSEA < 0.06.

Results

Validating the systemizing scale

EFA was carried out for one-factor, two-factor, and three-factor models. The one-factor model explained 18.85% of the variance and had a poor fit to the data, with $X^2(54) = 151.73$. The scree plot indicated that the optimal model is either a two-factor or three-factor model. The two-factor model explained 25.86% of the variance but had an inadequate fit, $X^2(43) = 96.59$.

The two factors were correlated ($r = 0.46$), and none of the items cross-loaded, although some items had low loadings (i.e., below 0.40). The three-factor model explained 31.72% of the variance and had an adequate fit to the data, with $X^2(33) = 43.69$, $p < 0.001$. Since the Mardia normalized coefficient was low, the results that we are reporting here come from the ML method. We selected the three-factor model and tested it using CFA. The statistics (S-BSS/df = $16.99/17 = 1.0$; CFI = 0.99; RMSEA = 0.03, 90% CI [0.00, 0.06]) indicate a good fit. Upon examining the content of the eight items that loaded on these three factors, we concluded that factor F1 assessed "interest in understanding technology," factor F2 assessed "interest in reports on science," and factor F3 assessed "understanding graphs/diagrams." Table 1 shows the factor loadings (standardized solution) and highlights how the indicators synonymous with these factors were computed. These factors differ from the four factors of technicity, topography, DIY, and structure found by Ling et al. (2009). The reliability for the eight-item systemizing scale in the current study was acceptable ($\alpha = 0.71$).

With data drawn from the confirmatory sample, we then proceeded to compute factor loadings of items in the three scales assessing the mediating variables: learning anxiety (A), intrinsic motivation (M), and self-efficacy (S). Table 2 displays the factor loadings and explains how the various indicators of these three mediating variables were computed. Model fit statistics shown in Table 2 indicate an adequate fit.

Testing the hypothetical model

Preliminary analyses

As outlined in Table 3, all correlations among the study variables were in the expected directions and similar for males and females.

Through univariate ANOVA, we compared Canada and Sweden on systemizing, anxiety, self-efficacy, intrinsic motivation, and achievement. There were no differences in systemizing, anxiety, achievement, or perseverance between the two countries. However, the mean differences in self-efficacy (Canadians, $M = 3.09$; Swedes, $M = 2.88$; $F(1, 1721) = 81.335$, $p < 0.001$) and intrinsic motivation (Canadians, $M = 3.08$; Swedes, $M = 2.83$; $F(1, 1722) = 28.589$, $p < 0.001$) were significant, with effect sizes at 0.02.

The results from tests of univariate ANOVA comparing males and females on systemizing, anxiety, self-efficacy, intrinsic motivation, perseverance, and achievement are displayed in Table 4. As expected, the mean difference in systemizing between males ($M = 3.11$) and females ($M = 2.70$) was significant, as were the mean differences in anxiety (males, $M = 1.83$; females, $M = 2.21$), self-

Table 1 Validation of the systemizing scale

Factor items	F1			F2		F3		
	Q1	Q2	Q7	Q4	Q6	Q3	Q5	Q8
Factor loadings	0.450	0.654	0.730	0.538	0.873	0.382	0.693	0.466
Indicators	SYS1			SYS2		SYS3		

Model fit statistics: CFI = 0.99; S-BSS = 16.99 (df = 17); RMSEA(CI) = 0.025(0.001, 0.060). Correlations between indicators: r(SYS1,SYS2) = 0.685; r(SYS1,SYS3) = 0.800; r(SYS2,SYS3) = 0.507. F1 = interest in understanding technology; F2 = interest in reports on science; F3 = understanding graphs/diagrams. Q1–Q8 correspond to the original reduced scale, which is reported in Jungert and Koestner (2015)

Table 2 Computation of indicators for learning anxiety, intrinsic motivation, and self-efficacy

	Learning anxiety				Intrinsic motivation				Self-efficacy				
Items	Q02	Q08	Q05	Q07	Q2	Q7	Q12	Q16	Q12	Q20	Q5	Q15	Q6
Factor loadings	0.670	0.797	0.679	0.699	0.790	0.872	0.891	0.765	0.735	0.429	0.702	0.682	0.731
Indicators	ANX1		ANX2		INT1		INT2		SEF1			SEF2	

Model fit statistics: CFI = 0.94; S-BSS = 207.54 (df = 62); RMSEA(CI) = 0.068(0.058, 0.078). Q1–Q20 correspond to the questionnaire used in this study regarding learning anxiety (adapted from AEQ; Pekrun et al., 2002) and to the original scales regarding intrinsic motivation (AMS; Vallerand & Bissonnette, 1992) and self-efficacy (MSLQ; Pintrich, Smith, Garcia, & McKeachie, 1991)

efficacy (males, $M = 3.12$; females, $M = 2.96$), and perseverance (males, $M = 3.20$; females, $M = 3.04$). Conversely, mean achievement levels between males ($M = 0.17$) and females ($M = 0.08$) were not significantly different. These results indicate that more females were choosing not to pursue a STEM program in college despite performing at a similar level as their male counterparts in their STEM courses. Taken together, these mean-level differences provide initial support for our hypothesis that cognitive style may account for lower female perseverance in STEM.

Using CFA to examine the instruments

The LM test indicated that one variable (ZPHYS, z-score in physics) cross-loaded on two factors, achievement and anxiety, in both male and female samples. It is justifiable to let the physics scores cross-load on anxiety and achievement as we measured learning anxiety (i.e., anxiety experienced when trying to learn physics as opposed to test anxiety), and research has shown that students frequently report being anxious learning physics and mathematics (e.g., Efklides and Volet 2005; Pekrun and Linnenbrink-Garcia 2012). Ad hoc modifications of each model resulted in differences in chi-square that were highly significant ($p < 0.001$) for both genders. Table 5 shows estimates of factor loadings for all indicators separated by gender. The test of invariance of factor loadings across genders showed that the probabilities of improving the fit by releasing any constraints ranged from 0.23 to 0.96.

Calibrating and validating the model

Female and male calibration samples were used to assess the adequacy of the fit of the model. Note that given the results of the CFA, the variable ZPHYS was always cross-loaded on anxiety and achievement in all subsequent tests. The model fit statistics for the female calibration

Table 3 Zero-order correlations among study variables for females (top right) and males (bottom left)

	1	2	3	4	5	6
1. Systemizing	–	− 0.26***	0.33***	0.42***	0.11*	− 0.03
2. Anxiety	− 0.31***	–	− 0.41***	− 0.27***	− 0.10*	− 0.18**
3. Self-efficacy	0.34***	− 0.46***	–	0.48***	0.20***	0.35***
4. Intrinsic motivation	0.41***	− 0.32***	0.49***	–	0.20***	0.20***
5. Perseverance	0.10*	− 0.15**	0.22**	0.26***	–	0.34**
6. Achievement	0.11**	− 0.31***	0.38***	0.23***	0.40***	–

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 4 Descriptive statistics and mean-level gender comparisons

Construct	Female M	SD	Male M	SD	F	p	Partial η^2
Systemizing	2.70	0.48	3.11	0.48	199.6	< 0.001	0.159
Anxiety	2.21	0.77	1.83	0.69	123.14	< 0.001	0.066
Self-efficacy	2.96	0.56	3.12	0.60	32.51	< 0.001	0.018
Intrinsic motivation	3.04	0.68	3.01	0.72	0.57	0.451	0.000
Perseverance	3.04	1.10	3.20	1.08	5.82	0.016	0.005
Achievement	0.08	0.80	0.17	0.80	3.23	0.07	0.003

sample ($n = 243$; S-BSS/df = 88.09/58 = 1.52, $p < 0.001$; CFI = 0.97; RMSEA = 0.05, 90% CI [0.03, 0.07]) and the male calibration sample ($n = 276$; S-BSS/df = 79.05/58 = 1.36, $p < 0.001$; CFI = 0.98; RMSEA = 0.04, 90% CI [0.02, 0.06]) indicated a good fit. Subsequently, the invariance of path coefficients in the model was tested across calibration and validation samples for both genders separately. In the case of females, the LM test indicated that the probability of improving the model fit by releasing any of the constraints varied from 0.07 to 0.90, and the model fit statistics (S-BSS/df = 205.43/131 = 1.57, $p < 0.001$; CFI = 0.97; RMSEA = 0.05, 90% CI [0.04, 0.06]) indicated that the model fit the calibration sample and the validation sample equally well. Hence, the female calibration and female validation samples were combined into one female sample. Similar results were obtained with tests of invariance across calibration and validation samples for males: the probability of improving the fit ranged from 0.31 to 0.90, and the model fit statistics (S-BSS/df = 206.35/131 = 1.58, $p < 0.001$; CFI = 0.97; RMSEA = 0.05, 90% CI [0.03, 0.06]) warranted combining the male calibration and male validation samples.

Testing the model and examining gender invariance

For both genders, LM tests and W tests revealed that modification of the models was unnecessary. When path constraints were imposed, the LM test showed that one constraint

Table 5 Standardized solution: factor loadings for each gender

Model fit statistics: CFI = 0.982; S-BSS = 179.2626 ($df = 94$); RMSEA(CI) = 0.042(0.032, 0.051)

Indicators	Female	Male
Achievement		
ZCHEM	0.831	0.847
ZMATH	0.848	0.837
ZPHYS	0.762	0.746
Anxiety		
ANX1	0.708	0.740
ANX2	0.956	0.833
ZPHYS	− 0.223	− 0.219
Self-efficacy		
SEF1	0.747	0.806
SEF2	0.881	0.867
Systemizing		
SYS1	0.656	0.652
SYS2	0.523	0.484
SYS3	0.488	0.510
Intrinsic motivation		
INT1	0.910	0.873
INT2	0.890	0.932

was untenable. Although CFI rose from 0.973 to 0.975 when the constraint on the path coefficient between anxiety and self-efficacy was released, the scaled chi-square difference was significant ($p = 0.018$). Figure 2 shows all paths.

R^2 values indicated that the model explained 22% (24% for females) of the variance in perseverance and achievement. Furthermore, this model explains variance in intrinsic motivation [41% (37%)], self-efficacy [41% (46%)], and learning anxiety [14% (21%)]. As hypothesized, systemizing positively predicted intrinsic motivation (males: $\beta = 0.64$, females: $\beta = 0.61$) and negatively predicted learning anxiety (males: $\beta = -0.38$, females: $\beta = -0.46$). Self-efficacy was positively predicted by intrinsic motivation (males: $\beta = 0.43$, females: $\beta = 0.42$) and negatively predicted by learning anxiety (males: $\beta = -0.38$, females: $\beta = -0.43$). Furthermore, self-efficacy positively predicted achievement (males: $\beta = 0.47$, females: $\beta = 0.49$), and in turn, intention to persist was positively predicted by achievement (males: $\beta = 0.34$, females: $\beta = 0.34$) and intrinsic motivation (males: $\beta = 0.26$, females: $\beta = 0.27$).

Discussion

Drawing from E–S theory, SDT, social cognitive theory, and the control–value theory of achievement emotions, the present investigation was designed primarily to determine if systemizing cognitive style predicted students' academic achievement and intentions to persist in STEM education. Prior to testing the hypothesized model, we endeavored to examine the psychometric properties of the shortened version of the SQ scale, which had previously been pilot tested but needed additional validation. Using EFA and CFA, three factors were identified and confirmed. The items that comprised these three factors were labeled *interest in understanding technology*, *interest in reports on science*, and *understanding graphs/diagrams*.

We then tested the hypothesized model, which indicated that the impact of systemizing cognitive style on achievement and persistence would be mediated by intrinsic motivation, learning anxiety, and STEM self-efficacy. As expected, the results of the SEM analyses provided support for all study hypotheses. Consistent with past research (Zeyer et al. 2012, 2013), systemizing positively predicted intrinsic motivation. As such, high systemizers reported feeling more intrinsically motivated to study science compared to low systemizers. From an
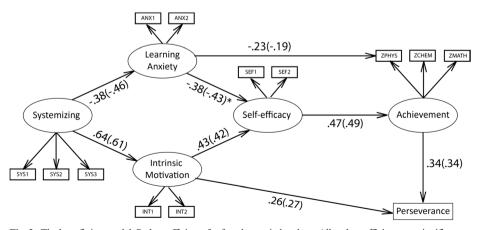

Fig. 2 The best-fitting model. Path coefficients for females are in brackets. All path coefficients are significant at $p < 0.05$. The asterisk indicates pathways where gender invariance was not obtained

early age, individuals with a high SQ display an enhanced propensity for scientific inquiry (Baron-Cohen 2003), and our results suggest that high systemizers transitioning to college continue to perceive STEM studies as intrinsically rewarding. Furthermore, systemizing negatively predicted anxiety, indicating that low systemizers appear to experience higher anxiety while studying science relative to high systemizers. Low systemizers may lack the drive to examine mechanical and natural systems, and attempting to comprehend such systems is likely to cause increased anxiety.

Regarding the second set of hypotheses, results revealed that self-efficacy was negatively predicted by anxiety and positively predicted by intrinsic motivation. Consistent with social cognitive theory (Bandura 1997) and recent research (Nie et al. 2011), students who experienced more anxiety had lower STEM self-efficacy relative to their peers who experienced little anxiety. Students' perceptions of their ability to succeed in their STEM courses were therefore adversely affected by their STEM-related anxiety. Conversely, more intrinsically motivated students had higher perceived self-efficacy compared to students lacking intrinsic motivation. In line with previous findings (Bryan et al. 2011), our results suggest that students with an inherent desire to immerse themselves in their science courses are more likely to believe they can succeed relative to students with externally regulated motivation.

In line with our hypothesis, self-efficacy had a strong, positive effect on academic achievement, consistent with social cognitive theory (Bandura 1997) and supports numerous studies that have found direct associations between self-efficacy and academic achievement in science (Glynn et al. 2011). Conversely, the results of our model did not support a direct link between self-efficacy and intention to persist likely due to the notably strong effects of achievement (males: $\beta = 0.34$, females: $\beta = 0.34$) and intrinsic motivation (males: $\beta = 0.26$, females: $\beta = 0.27$). We did test for a direct link between self-efficacy and intention to persist, but the results were not significant. Instead, self-efficacy may indirectly predict intention to persist in STEM in college through performance in high school or junior college STEM courses.

Finally, in line with the hypotheses, intrinsic motivation and achievement positively predicted intention to persist. Students with higher levels of intrinsic motivation were more likely to indicate that they would enroll in a STEM program in college compared to their peers who were lacking in intrinsic motivation. Likewise, students who obtained higher grades in high school or junior college STEM courses were also more likely to indicate that they would persist in STEM in college relative to those students who struggled academically. These findings are consistent with past research on perseverance in STEM (Heilbronner 2011; Wang 2013) showing motivation and achievement to be important predictors of students' willingness to pursue a STEM major in higher education. On the other hand, our model did not contain a significant path between intrinsic motivation and achievement although there was an indirect path via self-efficacy. Although past findings are inconsistent regarding the motivation-achievement relationship among adolescents (Baker 2003; Burton et al. 2006), the lack of a significant relationship herein may be the result of our failure to account and control for other forms of motivation. Thus, future research is needed to examine the longitudinal relations among intrinsic motivation and academic achievement while controlling for other known predictors as well as baseline levels of these constructs.

Our findings indicate that being a high systemizer is associated with positive motivational, emotional, and academic outcomes in students who study STEM in high school and junior college. Our model shows that systemizers are more likely to succeed academically and persevere in their STEM studies because they are highly intrinsically motivated to learn science and experience low anxiety when attempting to learn, which in turn leads to high

self-efficacy in science. Low systemizers, on the other hand, might experience high anxiety while studying, which likely leads to low STEM self-efficacy, low achievement, and hence to abandonment of STEM studies. This may also explain the negative loading of anxiety on achievement in physics. This covariance is best explained by the fact that low systemizers who have high anxiety when studying physics are more likely to receive lower grades in physics, whereas high systemizers have low anxiety when studying physics and are more likely to receive high grades in physics. It is also likely that low systemizers are less intrinsically motivated.

Concerning the gender gap in STEM enrollment and perseverance in higher education, our findings revealed that the model was reliable and valid for both females and males with only one significant gender difference in how the model was confirmed. For females, the negative path between learning anxiety and self-efficacy was stronger, suggesting that in the case of a male and female student with equally high level of learning anxiety, the female's self-efficacy would be lower. This finding is in line with existing academic emotion research in STEM (Goetz et al. 2013) highlighting gender differences in state anxiety and perceptions of competence despite equivalent levels of objective academic performance. One potential explanation may be the aversive effects of gender-based stereotype threats on females' perceptions of how they should think and feel towards STEM-related activities and outcomes (Smith and Hung 2008). Moreover, such findings indicate the need for intervention research that addresses the potential maladaptive effects of negative emotions on motivational variables in STEM students.

In line with E–S theory and past empirical research (Auyeung et al. 2012), on average, male students in the current study exhibited significantly higher systemizing scores relative to females. If males do in fact have a partly biological predisposition to be more adept at systemizing, and if a systemizing cognitive style corresponds with the skills needed to be successful in math-intensive STEM domains, then male students should perform better, on average, in math-intensive STEM courses throughout childhood and throughout their lives. However, while males had significantly higher intentions to persist in STEM into college, there was no significant gender difference in our aggregated STEM achievement outcome, which is consistent with existing meta-analytic findings (Hyde et al. 2008). This suggests the existence of other factors, above and beyond cognitive style, that influence STEM achievement. We sought to investigate potential psychosocial and affective influences that may mediate the intention to persevere in STEM into college, and that may explain the complicated relationship between gender, cognitive style, and achievement. We hypothesized that intrinsic motivation, anxiety, and self-efficacy were especially salient forces in math-intensive STEM domains. However, this limited set of variables clearly does not paint the whole picture, and additional research is needed to explain why we did not find a gender difference in achievement but a gender difference in persistence.

Finally, although the gender gap in STEM has decreased during the last years, and female students compose the majority of medical and health science degrees in many countries, they are still underrepresented in the most mathematically intensive fields. The current study could inform future trends in the gender gap in STEM. For example, by exposing adolescents to the different majors and careers they can pursue in STEM, it may serve to improve students' understanding of what these pathways and professions can offer. Explaining how STEM fields can be collaborative, innovative, and beneficial to society may make careers in STEM more appealing and attainable to female students during the formative years of their education (Diekman et al., 2011). In addition, it is important to provide female students with more female role models to increase positive attitudes towards STEM (Stout et al., 2011) and encourage

female students to aspire towards STEM careers. STEM departments in universities can also inspire and support female students by creating stronger STEM networks that can provided intergenerational peer support. Ideally, this process would introduce girls to STEM role models in elementary school to foster positive female attitudes towards STEM as early as possible (Wang and Degol, 2017).

Implication and limitations

Our findings have potential practical implications for teachers and students in STEM. For instance, instructors should be cognizant of how instructional design can impact students' cognitive style, and thus their intrinsic motivation and learning anxiety. Low systemizers are people who shun daily activities that would give them practice at recognizing patterns and figuring out how things function in relation to the physical world. When they enroll in STEM studies, their skills at performing such tasks are likely to be low, and consequently, they may experience a high cognitive load. Such students would probably benefit if their teachers developed instructional designs that decreased their cognitive load. Furthermore, low systemizers may need more time practicing and learning certain topics to develop their skills and increase their comfort level. They may also benefit from having access to worked-out examples to provide them with sufficient guidance.

Learning anxiety is typical when a student faces a novel task. To minimize the adverse effects of this emotion, teachers could aim to create a collaborative learning environment. Students observing peers coping with anxiety while in a collaborative setting can learn from the experience. A combination of cooperation and competition could also be considered by professors because it may facilitate motivation and performance (Tauer and Harackiewicz 2004). Professors can also "bring anxiety out of the closet." Referring to concepts as being "difficult to master" may help students to accept that a high level of anxiety is normal.

Finally, there are a few limitations that need to be considered. First, intention to persist was measured with a single self-report item asking students to indicate their intentions to continue studying science in college, rather than using objective academic records indicating their enrollment status, program choice, major, etc. Second, our study was cross-sectional in nature, and despite utilizing structural equation modeling to test our hypotheses, future research is warranted that employs longitudinal designs. A longitudinal study could follow students throughout their education and even into their careers to investigate how a systemizing cognitive orientation is related to outcomes such as motivation, self-efficacy, and performance in multiple contexts over time. Furthermore, longitudinal data allow examining reciprocal effects between constructs. Third, although the present study combined constructs from four diverse theoretical perspectives, our model was ultimately limited to a small set of motivational and dispositional predictors of STEM achievement and persistence. Future research that examines the role of additional psychosocial variables is encouraged, such as parental support, social involvement in the school, or peer mentoring. Fourth, we utilized a non-random selection of participants, and a self-selection mechanism was utilized to assign participants to the model-validation or scale-validation samples. Finally, this study used a new, shortened version of the SQ with only eight items. It is important that future research replicate this study using the full SQ (Baron-Cohen et al., 2003) to investigate whether the results remain consistent with the full version of the scale.

In conclusion, our findings suggest that a systemizing cognitive style impacts high school and junior college students' intrinsic motivation and learning anxiety in STEM, which in turn

affect their self-efficacy, academic achievement, and intention to persist. Our results offer evidence for the importance of cognitive style when examining student achievement and perseverance in STEM programs, but we stress that cognitive style is a dispositional predictor that does not operate in a vacuum. When examining gender disparity in STEM education, researchers should be considerate of the plethora of environmental or situational influences and how they interact with other predictors. Moreover, it is important to communicate these findings to educators so that they may adapt their instruction accordingly to promote long-term academic ties to STEM.

Appendix. Systemizing cognitive orientation items

Q1. I am not interested in understanding how new technology (e.g., wireless communication) works. (R).

Q2. I am fascinated by how machines work.

Q3. I find it easy to read and understand maps.

Q4. I do not tend to watch science documentaries on TV or read articles about science. (R).

Q5. I find it easy to understand instruction manuals for putting things together.

Q6. I rarely read web pages or articles about new technology. (R).

Q7. If I were buying a computer, I would want to know the exact details of its technical specifications (e.g., hard drive capacity or processor speed).

Q8. I find it difficult to interpret a graph if it does not have an explanation. (R).

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Current themes of research:

Social psychology. Educational psychology. Organizational psychology, primarily focusing on motivation, self-efficacy, teacher support, parental support, school bullying and empathy.

Most relevant publications in the field of Psychology of Education:

Jungert, T. & Koestner, R. (2015). *Science adjustment, parental and teacher autonomy support and cognitive orientation*. Educational Psychology, 35, 361–376.

Jungert, T., Hesser, H., & Träff, U. (2014). *Contrasting two models of academic self-efficacy—domain-specific versus cross-domain—in children receiving and not receiving special instruction in mathematics. Scandinavian Journal of Psychology, 55,* 440–447.

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Current themes of research:

Motivational strategies in academic settings, academic emotions, and motivational intervention programs targeting post-secondary students. Most recently, a focus on how students experience academic emotions. Specifically, my doctoral research investigates how students cope with boredom in educational contexts and across educational levels.

Most relevant publications in the field of Psychology of Education:

Simon, R. A., Aulls, M. W., Dedic, H., Hubbard, K. A., & Hall, N. C. (2015). *Exploring student persistence in STEM programs: A motivational model. Canadian Journal of Education, 38*(1), 1–27.

Hubbard, K. A., Wang, H., & Hall, N. C. (2016, April). *Persisting in STEM into university: The role of emotions in physics and chemistry. American Educational Research Association*, Washington, DC.

Hubbard, K., Sverdlik, A., Bieg, M., & Hall, N. C. (2014, August). *Narcissism, high self-esteem, and attributional retraining: A risky combination? American Psychological Association*, Washington, DC.

Hubbard, K., Simon, R., Hall, N. C., & Wang, H. (2014, July). *Exploring student persistence in STEM programs: A motivational model. Gender and STEM Network Conference*, Berlin, Germany.

Hubbard, K., Maymon, R., Astahova, M., & Hall, N. C. (2014, April). *Online attributional retraining and self-esteem: Assessing cognitive, emotional, and learning outcomes in college students. American Educational Research Association*, Philadelphia, PA.

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Current themes of research:

Focus on the decreasing enrollment and rising attrition in post-secondary STEM degree programs, particularly for women. Themes include studies on motivation, self-efficacy, emotion, students' persistence and achievement in

science and students transitioning from high school to junior college. More recently, the interests involve to create software for young children (grade 1) to learn mathematics.

Most relevant publications in the field of Psychology of Education:

Lysenko, L., Rosenfield, S., Dedic, H., Savard, A., Idan, E., Abrami, P. C. ... Naffi, N. (2016). *Using interactive software to teach foundational mathematical skills. Journal of Information Technology Education: Innovations in Practice, 15*, 19–34.

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Current themes of research:

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Most relevant publications in the field of Psychology of Education:

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