Brain type or Sex Differences?

A Structural Equation Model of the Relation between Brain type, Sex, and Motivation to Learn Science

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Abstract

Sex is considered to be one of the most significant factors influencing attitudes towards science. However, the so-called brain type approach from cognitive science suggests that the difference in motivation to learn science does not primarily differentiate the girls from the boys, but rather the
so-called systemisers from the empathizers. The present study investigates this hypothesis by using structural equation modelling on a sex-stratified sample of 500 male and female students of secondary II level. The results show, that the motivation to learn science is directly influenced by the systemizing quotient SQ, but not by sex. The impact of sex on the motivation to learn science, measured by five key concepts, only works indirectly, namely through the influence of sex on the SQ. The empathizing quotient (EQ) has no impact at all on the motivation to learn science. The SQ explains between 13 and 23 percent of the variation of the five key constructs. In female students, the impact of the SQ is very similar for all key concepts. In male students, it is highest for self-efficacy and lowest for assessment anxiety. The motivation to learn science is significantly larger for male students in all involved SMQ key concepts, but the difference is small. The interpretation of these findings and conclusions for science teaching and further research are discussed.

**Keywords:** Motivation; Cognition; Brain type; Attitudes; Quantitative research; Secondary school; Sex; Gender

**Introduction**

One of the major causes for concern in science education is the ‘swing away from science’ in many countries (Osborne, Simon, & Collins, 2003). Issues of motivation and attitudes are therefore particularly relevant in science (PISA, 2006). However, “whilst science and technology are often seen as interesting to young adolescents, such interest is not reflected in students’ engagement with school science that fails to appeal to too many students.” (Osborne & Dillon, 2008, p. 15). There is empirical evidence of factors for this low interest in school science, such as a lack of perceived relevance, a failure of narrative qualities in science education, a lack of
pedagogical variety, a less engaging quality of teaching in comparison to other school subjects, a male-oriented content, and an assessment system that encourages rote and performance learning rather than mastery learning for understanding (ebd.).

What these factors have in common is that their focus lies on the teaching process and its impact on student’s motivation to learn science. Only a minority of studies try to elaborate on students’ characteristics that may or may not motivate them for learning science. If they do, then their approach is mostly to interpret the lack of motivation in terms of a clash between the culture of school science and students’ life world culture (Aikenhead, 2000), or between scientific values and students’ personal values (Haste, 2004). Also when it comes to gender differences (which are indeed well known in science education), then a cultural approach is common (Parker, Rennie, & Fraser, 1996; Weinburgh, 1995).

The same holds for the approach of so-called cognitive styles, which refers to recurring patterns of perceptual and intellectual activity or, as defined by Riding and Rayner (1998), to an individual's preferred approach to organizing and representing information. Research findings indeed indicate that culture is an important socialization factor in students’ differences in cognitive styles (Zhang & Sternberg, 2006) and, generally, it has been asserted that how children are socialized is a critical factor contributing to their performance on any test of cognitive style (Witkin & Goodenough, 1981).

Compared to these classical attempts to understand attitudes and motivation to learn science, the brain type approach, which this study is committed to, suggests a different point of view. The concept of brain type was originally regarded within the field of autism research (Baron-Cohen, 2002). Based on the observation that people with Asperger’s syndrome (a highly skilled form of autism) had high “folk physical” abilities but were impaired in their “folk psychological” abilities, Baron-Cohen and colleagues developed a cognition concept proposing the interplay of
two core psychological dimensions: systemizing (S) and empathizing (E) (Baron-Cohen, Knickmeyer, & Belmonte, 2005). Systemizing is the ability to understand and predict the law-governed universe, while empathizing is the ability to understand and predict the social world (Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003). The brain type is defined as the interplay between the two abilities. There exists a score EQ (empathy quotient) and a score SQ (systemizing quotient) to measure the empathizing and the systemizing dimension respectively. The brain type is basically calculated as a mathematically normalized difference of EQ and SQ (see below for a more detailed description).

The concept of brain type is reminiscent of the theory of cognitive styles in a number of aspects. Indeed Baron-Cohen and colleagues accept that a field-independent cognitive style supports a systemizing brain type. However, they work within a completely different paradigm assuming that human cognition is domain-specific, which usually assumes a strong neurobiological background of cognitive dispositions and an explicit cross-cultural stability of these traits (Hirschfeld & Gelman, 1994).

Indeed, research on cross-cultural stability of the E-S-system shows a striking similarity in the group differences of the EQ and the SQ and the proportions of the brain types from completely different cultures such as Japan and the UK, so that the authors conclude that the psychological patterns in the two cognitive dimensions revealed reflect neural universals.

Based on this brain type approach, Billington and colleagues investigated students in physical sciences and humanities (Billington, Baron-Cohen, & Wheelwright, 2007). They found that the brain type was a better predictor for entry either into physical sciences or humanities than the
students’ sex\(^1\), which is also a predictor albeit a less accurate one. From their results, Billington and colleagues interpreted perceptions towards natural science as fundamentally influenced by brain type rather than by gender. Thus, the difference between interest and motivation in natural sciences did not primarily differentiate the girls from the boys, but rather the so-called systemizers from the empathizers. The difference sometimes observed between the genders resulted from the tendency for girls to be empathizers and the boys systemisers.

In two pilot studies (Author 2010, Authors 2010), it was attempted to verify whether this hypothesis amongst high school students could be confirmed. In order to measure students' motivation for science classes, the SMQ was used, the Science Motivation Questionnaire, developed by Glynn and Koballa (2006). This questionnaire operationalizes motivation to learn science in a combined scale of six motivational constructs (see below). In both investigations, a significant sex difference for the motivation of students for science lessons could not be observed. However, in the first pilot (Authors 2010) that included N=77 students, a mean correlation of 0.35 between the SMQ and the brain type was found. In the second pilot (Author 2010) including N=44 students, not only the relationship between the SMQ and the brain type was tested, but also between its two dimensions EQ and SQ. This resulted in a fairly high correlation between the SMQ and the SQ of 0.5, and no significant correlation between the SMQ and the EQ.

From the results of these two pilot studies, the goal of the current study was developed, namely to confirm the hypothesis that the SQ is the basic factor of influence on the motivation to learn science and that the influence of sex on motivation to learn science is only indirect, namely through its influence on the SQ.

\(^{1}\) In this article, we consistently use the term “sex” instead of “gender”, because the concept of brain type is inherently biological. In most of the literature we quote, the authors use of the word gender when clearly they are referring to biological sex, a phenomenon that can be frequently be observed in the research of science education (Rennie, 2000).
In the following sections of this article, underlying concepts in motivation and interest will be introduced and secondly, the brain type theory will be presented. Then the methodological approach will be described and the research design will be explained. In a further chapter, the results with be presented and lastly, their meaning will be discussed. In the conclusion, counter arguments will be addressed and the consequences this research will have for science lessons and further research will be highlighted.

**Theoretical framework**

*Motivation*

In a review of the major literature about attitudes towards science and their implications, Osborne et al. (2003) report that studies measuring the attitude towards science have incorporated motivation towards science as one component of many including the perception of the science teacher, anxiety towards science, the value of science, self-esteem at science, enjoyment of science, attitudes of friends and peers towards science, attitude of parents towards science, the nature of the classroom environment, achievement in science, and fear of failure on course. In the here presented study, we use the theoretical motivation framework of Glynn and Koballa (2006) to provide comparability with their results. Thus motivation is defined as “… the internal state that arouses, directs, and sustains students’ behaviour towards achieving certain goals. In studying the motivation to learn science, researchers attempt to explain why students strive for particular goals, how intensively they strive, how long they strive, and what feelings and emotions characterize them in this process” (Glynn et al., 2007, p. 1090). Based on research within the social-cognitive motivational framework (Bandura, 2001), the authors identify six important motivational constructs that include intrinsic and extrinsic motivation, relevance to personal goals, self-determination, self-efficacy, and assessment anxiety (Glynn & Koballa,
The so-called Science Motivation Questionnaire (SMQ) (see p. 12 “Part B, motivation towards science”) reflects these six motivational constructs. Motivation towards science, as defined by these six constructs, overlaps with some of the components of the attitude towards science as determined in Osborne et al. (2003). However, the in-principle idea, namely that motivation towards science is an important component of the attitude towards science (a more complex, overarching concept) remains in place.

Glynn and Koballa (2006) add up the scores of the six motivational constructs to a score of global science motivation SMQ. This procedure is known to be often problematic because of questions of unidimensionality (cf. Gardner, 1995, 1996) and of cultural differences (cf. Dimmock, 2000). For example in the present case, the complex relationship between self-determination and extraversion (Rigby, Deci, Patrick, & Ryan, 1992) questions a linear relation between the constructs of extrinsic/intrinsic motivation and of self-determination on a conceptual level. Even if the unidimensionality of the original SMQ concept has been proven in one cultural context, the growing awareness of the need for cultural and contextual sensitivity when conducting empirical research (Dimmock, 2007) makes it unlikely that this unidimensionality will be conserved across cultures. Therefore, it was decided that in the present study, analysis should proceed in terms of separate scores of the six motivational constructs.

**Brain type**

**Definition of brain type.** Billington and colleagues define brain type based on a recent theoretical account of Baron-Cohen and colleagues (Baron-Cohen et al., 2005). It proposes two core psychological dimensions: systemizing (S) and empathizing (E) (Billington et al., 2007) corresponding to the “consciousness of the physical world” and the “consciousness of the mental world”, respectively (Baron-Cohen, 1999).
Systemizing describes the ability to perceive “physical things” and to understand these objects in terms of a system, which needs an ability to identify local details and their interaction and to abstract from Gestalt perceptual distracters. It is therefore defined as the drive to analyze the rules underlying a system, in order to predict its behavior. A system in this context is understood as an object showing a tripartite structure: It can always be analyzed in terms of so-called input – operation – output patterns, where inputs are initial states of the system, outputs as subsequent states of the system, and operations as actions that transform input states into output states. Defined in this general way, systems can be found in many different domains; technical (e.g. machines and tools), natural (e.g. weather system), abstract (e.g. mathematics), social (e.g. political system), spatial (e.g. map reading), and organisable (e.g. a taxonomy).

Empathizing is the ability to identify and perceive “mental states”, thus defined as a drive to identify another person’s mental states and to respond to these with a range of appropriate emotions. Empathizing thus has both a cognitive and an affective component (Baron-Cohen & Wheelwright, 2004; Davis, 1980). The cognitive component involves understanding another person’s thoughts and feelings and is also referred to as using a theory of mind (Wellman, 1990). The affective component of empathizing involves an emotional response that arises as a result of the comprehension of another individual’s emotional state (Eisenberg, 2002).

Every human being is considered to dispose of both of these psychological dimensions, empathizing and systemizing, but normally on a different level. Some individuals are rather systemizers (S>E) whilst others have a dominant empathizing perception (E>S). Others show a balanced type (E=S) of these two dimensions. The relation of E and S is called the brain type of the individual. The whole concept is called the E-S model.

In order to work with the E-S model, Baron-Cohen and colleagues developed two self-reporting questionnaires (see p. 11 “Part A, E-S-model”). The two questionnaires exist in different
versions, but each of these calculate a systemizing quotient (SQ) and an empathizing quotient (EQ) providing a measure of the individual’s capacity to use the two cognitive dimensions. The variable representing the brain type is essentially calculated as the normalized difference of the EQ and the SQ. Both questionnaires have been extensively tested for their validity and their reliability (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004).

One of the important research outcomes resulting from these questionnaires is that females on average have a stronger drive to empathize (E>S), whilst males on average have a stronger drive to systemize (S>E) (Baron-Cohen, 2002). The E>S relation for females only applies on average; thus there will always be individuals who are atypical for their sex. However, and this is the important point in the context of our study, the E-S theory also argues that, irrespective of their sex, if an individual’s systemizing is at a higher level than their empathizing (S>E), it is this profile that leads them into disciplines that require an analytical style to deal with rule-based phenomena (Billington et al., 2007). If this were true, then it could be that it is basically not sex that mostly influences the attitude towards science subjects, but the brain type that only on average coincides with the individual’s sex.

It is in this theoretical framework that two recent studies (Billington et al., 2007; Wheelwright et al., 2006) indeed showed, that physical science degree students scored significantly lower on the EQ and significantly higher on the SQ and suggested, that the academic subject one ends up studying may be better predicted by one’s brain type than by one’s sex.

**Method and Sample**

This study is organized in a descriptive and a structural equation modeling part. Classical descriptive statistics serve to characterize the population in terms of the established scales of SQ, EQ. Concerning the SMQ, descriptive statistics is used to substantiate the decision to use the
motivational subscales of this measure rather than the global SMQ measure. The inferential part will link the study to the two previous pilot studies. The SEM part finally is crucial and provides a confirmatory analysis of the hypothetic relation between SQ, EQ, sex and SMQ. To this aim, structural equation modelling was used (Byrne, 2010). The indirect effect of sex on the SMQ was tested by bootstrapping. The comparison between male and female students used multiple-group confirmatory factor analysis (De Beuckelaer, 2005). All the items were recoded in order to obtain positive factor loadings in the structural equation model. This is indicated by the suffix “rec” (for example SQ15_rec for item SQ15 recoded) in all calculations.

Sample
A sex stratified simple random sample of 500 students (250 boys and 250 girls) was selected out of about 800 students from two upper secondary schools. It was our intention to provide, as far as possible, a homogeneous cultural backdrop. To this end we chose two schools from the same region that are structurally, conceptually and culturally similar (see discussion part). As there are no private schools in our country, and every child principally has access to any school (depending on his/her school performance), the classes represented a general social background of the country. In this country, upper secondary school students cannot yet be classified as science or non-science students. Every student has to take part in all science and non-science disciplines. However, generally, theses schools prepare students for university. Normally, a student attends this type of school during six years. At the end of this school time, being then 18 years old on average, every student has to pass a final exam involving every subject of the curriculum, particularly also science subjects.

We investigated students of the last three grades, because only then they have enough experience in science courses to answer questions concerning their motivation to learn science. Their science
courses include physics, chemistry, and biology, besides mathematics as another prominent subject. For a more detailed account of the sample, see below (result part).

**Procedures and Measures**

**Procedure**

The classes were visited during their regular school time. They were informed about the study and they consented to participate. Every student filled in a questionnaire and received his personal results by e-mail if s/he applied for it. The questionnaires had already been adapted to our students and had also been tested for validity and reliability in the already mentioned pilot studies (Author 2010, Authors 2010)

**The Questionnaire**

**Part A, E-S-model.** In part A of our questionnaire, we used the German version of the SQ and the EQ questionnaire by Baron-Cohen (2003). Both the SQ and the EQ questionnaires are 60-item, forced choice format, containing 40 cognitive style items and 20 control items. The SQ asks questions such as “If I had a collection (e.g. Coins, CDs, stamps), it would be highly organized” and “When I learn a language I become intrigued by grammatical rules”. Similarly, the EQ asks items such as “I am good at predicting what someone will do” to measure cognitive empathy or “I usually stay emotionally detached while watching a film” to measure the affective component of empathy.

On both the EQ and the SQ, participants are asked to respond with “definitely agree”, “slightly agree”, “slightly disagree” or “definitely disagree”, and approximately half the items are reverse scored to avoid response bias. Scores on both the SQ and the EQ range from 0 to 80.
Based on psychometric data (cf. Baron-Cohen et al., 2005), an EQ from 0-32 is considered as low, 33-52 as average range (most women score about 47 and most men score about 42), 53-63 is above average, 64-80 is very high (Baron-Cohen, 2003).

A SQ of 0-19 is considered as low, 20-39 as average (most women score about 24 and most men score about 30), 40-50 as above average, 51-80 as very high (Baron-Cohen, 2003).

*Item reduction in EQ and SQ.* In order to be able to include SQ and EQ as single latent variables into the model, each of them had to undergo a substantial item reduction. Given the sample size and the number of SMQ items, five items at most for SQ and EQ, each, seemed to be adequate (Kim, 2005). To preserve a confirmatory approach, an exploratory factor analysis provided in Wakabayashi et al. (2006) was used to assign the five most highly loading items of each scale. These five items were used to operationalize the measurement model for the EQ and the SQ, as well. The results of the consequential confirmatory factor analysis are discussed below in the results’ paragraph.

*Part B, motivation towards science.* In Part B of the questionnaire, we asked students to respond to the 30 items of the Science Motivation Questionnaire (SMQ; Glynn & Koballa, 2006). The items were translated into German. The SMQ items (see Table 1) were developed based on the motivation concepts described earlier in this article. The SMQ items ask students to report on intrinsically motivated science learning (items 1, 16, 22, 27, and 30), extrinsically motivated science learning (items 3, 7, 10, 15, and 17), relevance of learning science to personal goals (items 2, 11, 19, 23, and 25), responsibility (self determination) for learning science (items 5, 8, 9, 20, and 26), confidence (self-efficacy) in learning science (items 12, 21, 24, 28, and 29), and anxiety about science assessment (items 4, 6, 13, 14, and 18). Typical items for this questionnaire
are “I enjoy learning science” (item 1) or “Earning a good science grade is important to me” (item 7) or “I am confident I will do well in the science labs and projects” (item 21). Students respond to each of the 30 randomly ordered items on a 5-point Likert type scale ranging from 1 (never) to 5 (always). Anxiety about science assessment items are reverse scored when added to the total, so a higher score on this component means less anxiety (Glynn & Koballa, 2006).

**Results**

**Descriptive Measures**

We computed statistical results by means of the Statistical Program for the Social Sciences, version 15.0 (SPSS). We investigated a simple random sample of 500 students. Since the sample had been stratified by sex, 250 students were male (50%) and 250 were female (50%). The mean age was $\text{m}_{\text{age}}= 17.28$ years (SD=1.28).

Cronbach alpha coefficients were $\alpha=0.831$ for SQ (40 items), and $\alpha=0.864$ for EQ (40 items) indicating that 91%, 83%, and 86%, respectively, of the variance of the total scores on these questionnaires could be attributed to systematic variance. This means that the questionnaires have preserved a high internal consistency (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004; Glynn & Koballa, 2006) in the new context.

For the SMQ, Cronbach alpha was $\alpha=0.912$ for SMQ (30 Items). For the subscales of the SMQ Cronbach alpha was $\alpha=0.833$ for intrinsically motivated science learning, $\alpha=0.623$ for extrinsically motivated science learning, $\alpha=0.796$ for relevance of learning science to personal goals, $\alpha=0.606$ for responsibility (self-determination) for learning science, $\alpha=0.859$ for self-efficacy (confidence) in learning science, and $\alpha=0.817$ for anxiety about science assessment. If 0.7 is used as a threshold of acceptable internal consistency (Cramer 1998), these results signify an acceptable internal consistency for the global scale and most of the subscales, but not for the
two subscales “external motivation” and “responsibility”. Moreover, as Table 1 shows, the matrix for the Pearson correlations between the subscales does not produce justification for the unidimensionality of the SMQ.

<table>
<thead>
<tr>
<th></th>
<th>IntMot</th>
<th>ExMot</th>
<th>RelGoals</th>
<th>Respons</th>
<th>SelfEff</th>
<th>AssAnx</th>
</tr>
</thead>
<tbody>
<tr>
<td>IntMot</td>
<td>1.000</td>
<td>0.544**</td>
<td>0.732**</td>
<td>0.445**</td>
<td>0.697**</td>
<td>0.432**</td>
</tr>
<tr>
<td>ExMot</td>
<td>1.000</td>
<td>0.665**</td>
<td>0.424**</td>
<td>0.496**</td>
<td>0.084</td>
<td></td>
</tr>
<tr>
<td>RelGoals</td>
<td>1.000</td>
<td>0.375*</td>
<td>0.560**</td>
<td>0.293*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respons</td>
<td>1.000</td>
<td>0.368**</td>
<td>0.115</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SelfEff</td>
<td></td>
<td>1.000</td>
<td>0.630**</td>
<td></td>
<td></td>
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<tr>
<td>AssAnx</td>
<td></td>
<td></td>
<td>1.000</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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

Table 1. Pearson correlation (2-tailed) between the subscales of the SMQ

For example, internal motivation and relevance to personal goals (.0732), and internal motivation and self-efficacy (.697) show the highest correlations but are far from linearity (this is consistent with theoretical considerations, cf. p. 3 of this article). Other subscales, such as external motivation and assessment anxiety, are not even correlated.

Given these results, technical deficiency of the global SMQ seems to be obvious. The SMQ appears to be an example of a global measure that shows a high Cronbach alpha result but not unidimensionality of the subscales (Schmitt, 1996). Moreover, some of the subscales do not even preserve their internal consistency in our dataset. These results confirm the theoretically motivated decision that the present study should proceed in terms of separate scores of the six motivational constructs. However, it must be pointed out that in terms of structural modeling, the
discussed deficiencies are of limited importance. In structural contexts descriptive measures are considered to be less adequate than the SEM results provided below (cf. Byrne, 2010).

Due to these considerations, we do not provide the descriptive measures for the global SMQ scale. Furthermore, we do not provide the descriptive measures of the six motivational constructs because population means of these scales are not known and the aim of this short descriptive statistics section is only to link our results to previous studies.

The mean EQ of our students ($M_{EQ}=40.8$, $SD=10.51$) is within the population average. The minimum was $EQ_{\text{min}}=11$, the maximum $EQ_{\text{max}}=70$ points. The mean SQ of our students ($M_{SQ}=23.55$, $SD=9.93$) was also in the population average, but rather low. The minimum was $SQ_{\text{min}}=5$, the maximum $SQ_{\text{max}}=68$ points. The brain type was balanced ($M_{BQ}=-0.21$, $SD=0.1$).

The examination of skewness of the SQ (0.5, $SD=.11$), the EQ (0.097, $SD=.11$), and the SMQ (-0.156, $SD=.11$) shows that our results met the assumption of univariate normality.

<table>
<thead>
<tr>
<th>Item</th>
<th>Wording</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Skewness</th>
<th>Std. Error</th>
<th>Kurtosis</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>SQ_04_rec</td>
<td>I am fascinated by how machines work</td>
<td>0</td>
<td>2</td>
<td>0.647</td>
<td>0.743</td>
<td>0.673</td>
<td>0.110</td>
<td>-0.903</td>
<td>0.219</td>
</tr>
<tr>
<td>SQ_12_rec</td>
<td>I find it difficult to understand instruction manuals for putting appliances together</td>
<td>0</td>
<td>2</td>
<td>1.214</td>
<td>0.727</td>
<td>-0.351</td>
<td>0.110</td>
<td>-1.052</td>
<td>0.219</td>
</tr>
<tr>
<td>SQ_13_rec</td>
<td>If I were buying a stereo, I would want to know about its precise technical features</td>
<td>0</td>
<td>2</td>
<td>0.694</td>
<td>0.770</td>
<td>0.587</td>
<td>0.110</td>
<td>-1.085</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_01_rec</td>
<td>I enjoy learning science</td>
<td>1</td>
<td>5</td>
<td>3.151</td>
<td>0.980</td>
<td>-0.268</td>
<td>0.110</td>
<td>-0.457</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_02_rec</td>
<td>The science I learn relates to my personal goals</td>
<td>1</td>
<td>5</td>
<td>2.913</td>
<td>1.065</td>
<td>0.002</td>
<td>0.110</td>
<td>-0.766</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_03_rec</td>
<td>I like to do better than the other students on the science tests</td>
<td>1</td>
<td>5</td>
<td>3.450</td>
<td>1.174</td>
<td>-0.359</td>
<td>0.110</td>
<td>-0.754</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_07_rec</td>
<td>Earning a good science grade is important to me</td>
<td>1</td>
<td>5</td>
<td>3.800</td>
<td>0.914</td>
<td>-0.536</td>
<td>0.110</td>
<td>-0.224</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_10_rec</td>
<td>I think about how learning science can help me get a good job</td>
<td>1</td>
<td>5</td>
<td>2.788</td>
<td>1.070</td>
<td>0.092</td>
<td>0.110</td>
<td>-0.805</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_13_rec</td>
<td>I worry about failing the science tests</td>
<td>1</td>
<td>5</td>
<td>3.228</td>
<td>1.085</td>
<td>-0.262</td>
<td>0.110</td>
<td>-0.525</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_14_rec</td>
<td>I am concerned that the other students are better in science</td>
<td>1</td>
<td>5</td>
<td>3.488</td>
<td>1.132</td>
<td>-0.554</td>
<td>0.110</td>
<td>-0.457</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_19_rec</td>
<td>I think about how I will use the science I learn</td>
<td>1</td>
<td>5</td>
<td>2.899</td>
<td>0.963</td>
<td>0.026</td>
<td>0.110</td>
<td>-0.343</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_21_rec</td>
<td>I am confident I will do well on the science labs and projects</td>
<td>1</td>
<td>5</td>
<td>3.506</td>
<td>0.917</td>
<td>-0.650</td>
<td>0.110</td>
<td>0.175</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_22_rec</td>
<td>I find learning science interesting</td>
<td>1</td>
<td>5</td>
<td>3.292</td>
<td>1.018</td>
<td>-0.148</td>
<td>0.110</td>
<td>-0.375</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_23_rec</td>
<td>The science I learn is relevant to my life</td>
<td>1</td>
<td>5</td>
<td>2.962</td>
<td>1.007</td>
<td>0.125</td>
<td>0.110</td>
<td>-0.531</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_24_rec</td>
<td>I believe I can master the knowledge and skills in the science course</td>
<td>1</td>
<td>5</td>
<td>3.683</td>
<td>0.850</td>
<td>-0.575</td>
<td>0.110</td>
<td>0.337</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_25_rec</td>
<td>The science I learn has practical value for me</td>
<td>1</td>
<td>5</td>
<td>3.010</td>
<td>0.933</td>
<td>0.010</td>
<td>0.110</td>
<td>-0.562</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_26_rec</td>
<td>I prepare well for the science tests and labs</td>
<td>1</td>
<td>5</td>
<td>3.403</td>
<td>0.946</td>
<td>-0.452</td>
<td>0.110</td>
<td>-0.207</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_27_rec</td>
<td>I like science that challenges me</td>
<td>1</td>
<td>5</td>
<td>3.018</td>
<td>1.129</td>
<td>0.040</td>
<td>0.110</td>
<td>-0.833</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_28_rec</td>
<td>I am confident I will do well on the science tests</td>
<td>1</td>
<td>5</td>
<td>3.357</td>
<td>0.955</td>
<td>-0.347</td>
<td>0.110</td>
<td>-0.331</td>
<td>0.219</td>
</tr>
<tr>
<td>SMQ_29_rec</td>
<td>Ich glaube, ich kann in den naturwissenschaftlichen Fächern sehr gute Noten erreichen</td>
<td>1</td>
<td>5</td>
<td>3.258</td>
<td>1.089</td>
<td>-0.272</td>
<td>0.110</td>
<td>-0.578</td>
<td>0.219</td>
</tr>
</tbody>
</table>

Table 2. Wording and Descriptive statistics of the SQ and SMQ items
Males had a considerably higher SQ ($M_{SQ_{male}} = 28.36$, $SD=9.01$) than females ($M_{SQ_{female}} = 17.74$, $SD=10.2$). The effect size $d=1.04$ of this highly significant difference ($p<.01$, t-test for equality of means, 2-tailed) is large (Cohen, 1988). Males had a lower EQ ($M_{EQ_{male}} = 37.74$, $SD=10.20$) than females ($M_{EQ_{female}} = 43.82$, $SD=8.32$). The effect size $d=.54$ of this also highly significant difference ($p<.01$, t-test for equality of means, 2-tailed) is medium (Cohen 1988). These results are comparable to former findings (Baron-Cohen et al., 2005).

Table 2 contains the wording of the SMQ and SQ items that were selected for the SEM process, along with the means, standard deviations and skewness of each item. It reveals that these items all meet the assumption of univariate normality.

**Structural equation models.** For the simultaneous test of the structural and measurement hypotheses, a causal structure was posited among the concepts of empathizing (EQ), systemizing (SQ), motivation to learn science (SMQ), and sex. The resulting structural equation model reflects the hypothesis, that the subconstructs (or, as they will be called: key concepts) of the SMQ are influenced by the SQ and by the EQ, and that sex only has an indirect (mimic) effect through its impact on the two latent variables EQ and SQ. Technically speaking, the model is a first order model, which is a direct consequence of the decision not to introduce the global SMQ measure. Because of the complexity of the empirical test, a two-step process was employed to confirm the first order model (Jöreskog, 1993). All the estimates were produced using AMOS 16.0 (Airbuckle, 2007) and the estimation method of maximum-likelihood. In the first step, the measurement models of the EQ, the SQ and the six key concepts of the SMQ were tested via confirmatory factor analyzes and were modified as necessary. As discussed in above, the five highest loading items of the SQ and the EQ (Wakabayashi et al., 2006) were used to
operationalize these two latent variables. For the latent variables of the six key concepts, the confirmatory factor analysis started with the five original items of each concept. All the models are congeneric, i.e. all the parameters are freely estimated.

In a second step, we directly tested the full structural model. It reflects the core hypothesis of this study, that the SQ and also the EQ have an impact on each key concept of the SMQ, and that the impact of sex is only indirect (mimic) via EQ and SQ. Figure 1 shows the basic structure of the full model at the start of the testing process (the items of the different constructs are omitted for better overview).
Figure 1: The basic structure of the full model at the start of the testing process

After an intensive analysis of the modification indices, significance tests, standard errors, and several intermediate model modifications, the structural equation model in Figure 2 is regarded as best fitting to the data.

Figure 2: Full structural Equation Model

The following is a discussion of modifications that were introduced after consideration of empirical and theoretical implications. It starts by describing some marginal modifications of the measurement instruments, before it discusses the two salient changes that the model has undergone during the optimization process, namely the deletion of the key concept 4 of the SMQ.
“self-determination”, and of the EQ, the empathizing quotient, as latent variables in the full model.

In the SMQ key concept 1, “Intrinsic motivation”, the items SMQ 16 (“The science I learn is more important to me than the grade I receive”) and SMQ 30 (“Understanding science gives me a sense of accomplishment”) were removed, because of their small loadings and/or lack of significance. The threshold of standardized factor loadings used to decide if an item should be deleted was 0.3 (Brown, 2006). The deletion of item 16 and 30 seems appropriate when taking into account that, firstly, grades play an important role in schools selecting for university and, secondly, that the culture of this country does not expect students to openly show satisfaction about grades and accomplishments.

The remaining factor loadings are now equally distributed around 0.75 to 0.8 (standardized estimates). An error correlation between SMQ1 (“I enjoy learning science”) and SMQ 22 (“I find learning science interesting”) has been established to improve the overall fit of the model. It seems reasonable to accept this modification, since the suggestion that a student who enjoys learning science also finds learning science interesting, and vice versa, seems to be adequate.

For the same reason, in key concept 2, “Extrinsic motivation”, the two items SMQ 15 (“I think about how my science grade will affect my overall grade point average”) and SMQ 17 (“I think about how learning science can help my career”) were removed. This seems again to be a cultural effect, because in this country, openly expressed career ambitions are often criticized.

In key concept 3, “Personal relevance”, remain three items. Item 11 (“I think about how the science I learn will be helpful to me”) has been deleted because of poor factor loading and also item SMQ 19 (“I think about how I will use the science I learn”), for the same reason. An error correlation between the errors of SMQ 23 (“The science I learn is relevant to my life”) and SMQ 25 (“The science I learn has practical value for me”) was introduced to improve the overall fit of
the model. It seems to express that our students conceive the relevance of science in their life in terms of practical value.

In key concept 5, Self-efficacy, item 12 (“I expect to do as well as or better than other students in the science course”), was removed because of poor factor loading. Again this fits the interpretation that, out of cultural reasons, our students avoid openly acclaining competition between peers.

In the final model, key concept 6, “Anxiety about science assessment”, consists only of two remaining items, namely SMQ 13 (“I worry about failing the science tests”) and SMQ 14 (“I am concerned that the other students are better in science”). Items 4 (“I am nervous about how I will do on the science tests”), 6 (“I become anxious when it is time to take a science test”), and 18 (“I hate taking science tests”) do not appear in the final model, which suggests that these students primarily worry about the results of the test and of their performance, more than having bad feelings about the testing situation itself.

All in all, these corrections of the measuring models included seem to be consistent and due to a cultural background that avoids exhibiting direct competition and career thinking, and interpreting assessment not in terms of emotional stress but of results and performance. These findings emphasize the importance of paying attention to cultural aspects of research findings when using methods, assumptions, models and theories drawn from elsewhere (Dimmock, 2007).

Besides these modifications of the measurement instruments, there is another modification introduced by the presented model, namely error correlations between the different key concepts. Some of these correlations are rather strong, such as, the error correlation between “Intrinsic motivation” and “Extrinsic motivation” (0.72), and the error correlation between Intrinsic motivation and Relevance to personal goals (0.9). We interpret these correlations as an expression of the mutual interdependence of the SMQ key concepts, particularly of the key
concepts “Intrinsic and extrinsic motivation”, and “Relevance for personal goals”. However, in this model, there are no cross-loadings between the key concepts, which suggests that they are indeed conceptually independent. This confirms the decision to abstain from using the global SMQ as an overarching concept and reproduces the findings in the correlation matrix of the key concepts as they are presented in the descriptive statistics’ paragraph.

The SQ is operationalized by three of the 5 initial items. The modification indices suggested strong cross loadings of the items SQ 5 („If I were buying a motorbike, I would want to obtain specific information about is engine capacity“), and SQ 20 („If I were buying a computer, I would want to know exact details about is hard drive capacity and processor speed“) and 33 („If I were buying a stereo, I would want to know about its precise technical features.“). This seems highly reasonable because these three items are similar on a content level and a structural level as well. We decided to keep item SQ 33, because it which is he highest loading item in the factor analysis of (Wakabayashi et al., 2006).

We now come to the important structural modifications of the presented structural model. They will be subject of an extensive theoretical and practical analysis below in the discussion paragraph, while here only results of the modelling process are presented.

A salient feature is the complete absence of the EQ, the empathizing quotient, in the diagram. This latent variable indeed showed only small and non-significant loadings on all other latent variables in the model. There was also no impact of sex on this latent variable. Its removal entailed an improved overall fit.

Key concept 4 of the SMQ, “Self-determination”, is also absent for the same reason in the final model. Neither the SQ, nor the EQ (before being removed), showed a significant loading on “Self-determination”, and the optimization process suggested no correlations between self-determination and the other SMQ key concepts, thus again supporting the revised approach that
abandons an overarching SMQ concept. Descriptive statistics had already pointed out a problem with self-determination, because this key concept had failed to be internally consistent. The factor loadings of the remaining measurement instruments are statistically highly significant (p<.01) and the corresponding signs concur with the hypotheses. The standardized estimates, from .53 to .86, confirm the formal validity of the individual items (see Bollen, 2002). The explained variances of the items vary between .28 and .69, a range of magnitudes that is acceptable. Descriptively the model works very well and this is confirmed by a goodness of fit index (GFI) of 0.940. The baseline comparison (CFI) is 0.964. From an inferential point of view, the model is quite compatible with the data (CMIN/DF=2.188. RMSEA<.005 and PCLOSE (.576) indicates a perfect fit (for the fit measures see Arbuckle, 1997, 551ff).

The standardized regression weights of SQ on the key concepts of the SMQ are considerably high (.441 on “Intrinsic motivation, .412 on “Extrinsic motivation, .377 on “relevance to personal goals”, .475 on “Self-efficacy”, and .355 on “Assessment anxiety”). Therefore, the explanatory power of the model is also relatively high, which is expressed in the squared multiple correlations. They indicate, that the impact of the SQ can explain 20% of the variance of “Intrinsic motivation”, 17% of “Extrinsic motivation”, 14% of “Relevance for personal goals”, 23% of “Self-efficacy” and 13% of the variance of “Assessment anxiety”. There is also a high factor loading of sex on the SQ. The standardized regression weight is negative (-0.53), because this variable represents “female” by the value 1, while 0 represents “male”. Therefore in this model males have a higher SQ (which fits with the result in the descriptive part of this study), and the impact of sex explains 28% of the variation of the SQ.

Given the good fit, the high amount of multiple square correlations, the high, equally distributed, and highly significant factor loadings, we consider this model to be appropriate as a full model of our theory. It reflects the theoretical background of the E/S theory. It confirms the hypothesis,
that the motivation to learn science is highly influenced by the systemizing cognition, while the EQ, the empathizing cognition, has no significant influence on this motivation. It also confirms the hypothesis of a non-direct, mimic influence of sex on the motivation to learn science, by influencing the systemizing quotient.

In order to calculate whether the difference of the factor loadings between the SQ and the five remaining key concepts of the SMQ are significant, models with constraints were compared. As a result, the effect of SQ on Self-efficacy is significantly the highest one (0.48, p<.001), while the impact of SQ on Intrinsic and Extrinsic motivation, relevance to personal goals, and assessment anxiety are do not significantly differ from each other (between 0.36 and 0.44).

The indirect effect of sex was calculated by bootstrapping. The standardized indirect effects of sex on the five remaining key concepts of SMQ are highly significant, but all of them are smaller than 0.3 (-0.233 for “Intrinsic motivation”, -0.217 for “Extrinsic motivation”, -0.199 for “Relevance to personal goals”, -0.251 for “Self-efficacy”, and -0.187 for “Assessment anxiety”). Thus the effect of sex on the key concepts is strictly indirect, since it turned out that there are no significant direct loadings of sex.

In order to compare the situation of male and female students, we used the method of simultaneous multiple group comparison, which allows an examination of the structure of the causal relations in both the measurement and the structural model (see Byrne, 2010). Firstly, a configural model (with no equality constraints imposed) was created by deleting the sex variable in the original full structural model. The fit of the configural model proved to be good, with CMIN/DF=1.667, CFI=.958, and RMSEA=.037., i.e. the hypothesized multigroup model was good fitting across male and female students. Secondly, the metric (measurement) and the scalar invariance (structural) model were created and tested for invariance. The fit of the measurement model was consistent with that of the configural model (CFI=.957; RMSEA = .036). The
difference test to the configural model yielded $\Delta \text{CMIN} = 17.254$, $p=.188$, which argues for metric invariance. The fit of the structural model was also consistent with that of the configural model (CFI=.952; RMSEA = .038). The difference test to the measurement model yielded $\Delta \text{CMIN} = 33.032$, $p=.001$. The CFI difference test produced $\Delta \text{CFI} = .007$, which argues for scalar invariance (Cheung & Rensvold, 2002). In this case, the intercept of SQ_12_rec had to be released to obtain a good result. It was concluded that our multigroup model displayed partial scalar invariance, which allows for a comparison of factor loadings and latent means between the groups of male and female students. Table 3 shows the Square multiple correlations and the implied means of the five key concepts of the SMQ, and the means of the SQ for both males and females.

<table>
<thead>
<tr>
<th></th>
<th>Square Multiple Corr. (explained Variance)</th>
<th>Implied Means</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>male</td>
<td>female</td>
</tr>
<tr>
<td>Intrinsic Motivation</td>
<td>0.161</td>
<td>0.174</td>
</tr>
<tr>
<td>Extrinsic Motivation</td>
<td>0.229</td>
<td>0.116</td>
</tr>
<tr>
<td>Relevance to personal goals</td>
<td>0.14</td>
<td>0.136</td>
</tr>
<tr>
<td>Self-Efficacy</td>
<td>0.056</td>
<td>0.204</td>
</tr>
<tr>
<td>Assessment anxiety</td>
<td>0.212</td>
<td>0.091</td>
</tr>
</tbody>
</table>

Table 3: Squared Multiple correlations and implied means of the five SMQ key constructs

The SQ of the male students ($M_{SQ}=1.35$) is twice as large as the SQ of the females ($M_{SQ}=0.62$). This difference is highly significant ($p<.01$). The means of the five motivational key concepts are slightly larger for the male students than for the females. As to the square multiple correlations of the SQ on the five SMQ key concepts, there are significant differences in “Extrinsic Motivation” (SMC$_{male}=0.23$ and SMC$_{female}=0.11$) and in “Assessment Anxiety” (SMC$_{male}=0.05$ and SMC$_{female}=0.10$).
Discussion

The results of this study are organized into a descriptive and a SEM part. The results of the descriptive part are consistent with what is already known about the E/S theory (Baron-Cohen et al., 2005), and it substantiates the theoretical expectation that the use of a global SMQ is problematic (see below). The female students tend to be empathizers, the male students systemisers. The population as a whole is balanced. These results fit those of many previous studies (Baron-Cohen et al., 2003; Baron-Cohen & Wheelwright, 2004).

The SEM part of our results provides a structural model that reflects and confirms the theoretical background of the E/S theory as well as reproduces and explains the already known relations. While in this model most of the original SMQ items could be used to operationalize the SMQ key concepts, a substantial item reduction had to be performed with the SQ. In the resulting full structural model, the SQ turns out to be operationalized by three items that are all concerned with attitudes towards technical devices: the interest in machines, the purchase of a new stereo, and the understanding of “instruction manuals”. This can be seen as both a quality and a flaw of the model.

It is a quality of the model insofar as it suggests a clear and straightforward interpretation of the SQ. Machines can be conceived as paradigmatic “prototypes” of systems and, in fact, in the already quoted exploratory factor analysis of the SQ (Wakabayashi et al., 2006), 7 of the 10 most loaded items are concerned with machines or technical systems in a strict sense. As described, the full questionnaire of the SQ includes systematic approaches towards various other life world domains, i.e. items that are concerned with systemizing cognition in various domains of everyday life, like reading books, playing games, and dealing with maps. Our model suggests that indeed
the attitude towards machines is the level playing field for males and females wherein the systemizing cognition most saliently articulates. It is exactly this that could be seen as a flaw of the same model. One could argue that the SQ only reproduces a person’s interest in machines and technical devices. It would then simply paraphrase the same (or a similar) latent variable as the SMQ. However, besides the fact that motivation to learn science and interest in machines seem to be two fairly well distinguishable attitudes, this seems to be also an undue shortcut when taking the full characterization of the SQ into account. The high internal validity of the SQ scale shows that it transports much more than only the interest in machines. The fact that this interest shows the highest factor loadings does not mean that other items are not important. Yet our model could indeed be interpreted in the sense that the drive to systemize is nothing else than “identifying the machine” in other systems, may they be biological, geographical or everyday life. The description of systems provided by Baron-Cohen (2003) in terms of input, mechanism, and output seems to support this interpretation. It must also be stressed that the concept of systemizing is basically a biological concept summarizing a large body of empirical research findings not only in psychology, but also in various bio-medical disciplines such as neurology, anatomy, and endocrinology (Baron-Cohen et al., 2005). We therefore contest that it is not a mere tautology, as it might appear at face value, when stating that a systemizing brain type predisposes to a high motivation to learn science. It is a statement on a stable attribute of personality - which includes that there is a valid and reliable way to test this attribute, something that again seems to be confirmed by the stable results and the high internal consistency that these tests demonstrate in our own studies. We therefore conclude that the interest in machines, in technical details of appliances and the ability to deal with technical instruction manuals is adequate as an operationalization of the
systemizing cognition and that our model indeed characterizes the impact of the SQ on the SMQ key concepts.

One aspect that has to be discussed in this context is the deficiency of the global SMQ measure, which has been postulated for theoretical reasons and has been confirmed in both descriptive and structural analyses. Descriptive analysis clearly supported the theoretical expectation of the global SMQ as not unidimensional and therefore it is problematic as a global measure. Moreover, not all of the subscales were internally consistent. The SEM process confirmed only five of the six subscales indicating that the subscale of “self-efficacy” did not reflect a latent variable and was thus omitted. “External motivation”, on the other hand, modelled a latent variable if only three items out of the five original items were preserved; this correction was explained by cultural considerations. In this way, the results of SEM supported resp. explained theoretical considerations and the findings of descriptive statistics in a consistent way and by means of a well fitting model.

Having clarified these preliminaries, there seem to be three salient aspects of the model that should now be discussed: the impact of the SQ on SMQ, the absence of an impact of the EQ on the SMQ, and the strictly indirect influence of sex on the SMQ.

The impact of the SQ on the motivation to learn science is high. It explains between 13% and 23% of the variance of the five involved key concepts of motivation. The more somebody systemizes, the higher is his/her intrinsic and extrinsic motivation, the more relevant learning science is for his/her personal goals, the better is his/her self-confidence in learning science and the lower is his/her assessment anxiety in science tests. The highest impact of SQ on SMQ was found in the self-confidence variable. The other factor loadings on Intrinsic and Extrinsic Motivation, Relevance to personal goals, and Assessment anxiety were slightly lower and not significantly different from each other. It seems to be reasonable that a strong systemizing ability
entails a high self-confidence towards learning science, if one recalls that systemizing in terms of the E/S theory is defined as a drive and ability to analyze the rules underlying a system, in order to predict its behavior. This seems to hold particularly true for male students, since the explained Extrinsic motivation variation is more than double in males than females.

Self-determination, the sixth SMQ key concept, does not appear in the model. This can be explained by pointing out, that self-determination is a personal trait, a kind of personal virtue that is not linked with the strength of a person’s systemizing drive. Moreover, this key concept failed to be internally consistent already in the descriptive analysis part.

Group comparison between male and female students revealed, that in females the impact of the SQ on all five SMQ key concepts is almost equal, while for males the impact on self-confidence is highest while the impact on Assessment anxiety is lowest. Male students seem to be less anxious of science tests than females, independently of how good they are at systemizing. This result supports the finding of Britner (2008) that girls reported higher levels of science anxiety than boys. The higher impact of the SQ on the self-confidence of the boys could also be interpreted in accordance with Zeldin, Britner and Pajares (2008) who showed that a higher SQ might lead to more mastery experiences, which was found to be the only significant predictor of boy’s self-efficacy in science, while for girls, social persuasions, vicarious experiences, and physiological states were better predictors of science self-efficacy.

The second salient feature, the absence of an influence of the EQ on the key concepts of the SMQ, has to be interpreted in a similar context. EQ is also a personal trait and the EQ questionnaire also contains 60 variables that proved to be of high internal reliability. The structural model suggests that there is no influence of the EQ on the SMQ. Empathizing is defined as a drive to identify another’s person mental states and to respond to these with one of a range of appropriate emotions, and this personal disposition seems to have no influence on the
motivation to learn science. This confirms our findings of the second pilot study, and it partially corrects the hypothesis originated in the work of (Billington et al., 2007). If it were the brain type as a whole, which influenced the motivation to learn science, then not only the SQ but also the EQ would be involved. Since the brain type is essentially calculated as the difference between the SQ and the EQ, a positive impact of the braint type on the five SMQ key concepts would entail a negative impact of the EQ on the key concepts. Such a negative impact could indeed be motivated from a theoretical point of view. If empathizing is the drive to deal with mental states, it could well be that a strong interest for mental things could, simultaneously, diminish the motivation to get involved with science, at least with science that is explicitly dedicated to physical things.

However, in our structural model, this is not the case. Here, the motivation to learn science is independent of a person’s drive to empathize. A strong empathizer can be poorly motivated to learn science, however her/his motivation can also be strong. It depends on her/his SQ. The same holds conversely for a low empathizer. This could be interpreted in two different ways. Firstly, one could argue (based on the aforementioned reflections), that general science simply has no nexus to empathizing at all and therefore does not affect the empathizing cognition of a person whatsoever. Another point of view could be that it is only the way of teaching general science in the investigated schools that has no effect on the empathizing dimension of the students at all (at least, it has no negative impact as suggested by previous research, which could also be seen as a positive point). From our data, it cannot be decided which interpretation is the correct one. We will come to this again in the conclusion of this article.

The third salient feature of our two models is the only indirect (mimic) effect of sex on the motivation to learn science. This is in fact the core hypothesis derived from the findings of Billington et al. (2007) and the main motivation for the here presented investigations. The
argument goes like this: The motivation to learn science depends primarily on the SQ of a person. If a student has a strong systemizing cognition, then this person will be motivated to learn science, independently from his/her sex. Because men tend to be stronger systemizers than women, men are prone to be more motivated to learn science. However, if a man is a weak systemizer, he is not motivated to learn science in spite of his being male. Men are, on average, more motivated to learn science than women, because they are, on average, stronger systemizers. The same holds conversely true for women.

This argumentation seems to be confirmed by our structural equation model. The indirect effect of sex on all SMQ key concepts is small, but highly significant. Due to these small indirect effects, the sex differences in the means of all motivational key concepts’ are only small, in spite of the male SQ mean being double that of the female SQ mean, these differences are only small. The male students show a significantly higher mean in all the SMQ key concepts than the females, which is consistent with the sex comparison of the overall SMQ in the descriptive result part. This is due to the small indirect effects of sex.

Conclusions

All in all, the here presented full structural model suggests the following situation. The motivation to learn science is directly influenced by the SQ, and indirectly by sex. SQ and sex together explain 13 to 23 percent of the variation of Intrinsic and Extrinsic Motivation, of Relevance to personal goals, of Self-confidence, and of Test anxiety, however there is no impact on Self-determination. In female students, the impact of the SQ is very similar for all key concepts. In male students, it is highest for self-determination and lowest for test anxiety. The motivation to learn science is significantly larger for male students in all involved SMQ key
concepts, but the difference is small. This is due to the small indirect effect of the considerably higher mean SQ of male students.

We are well aware, that in the real classroom situation, these structural relations will be blurred and transformed by cultural processes. Nevertheless, the here proposed EQ/SQ/SMQ model could shed more light on many unclear and contradictory results of many investigations into gender and motivation to learn science. In an investigated group of students, the situation can vary considerably, depending on the “SQ status” of the members of the group. One could well imagine that cultural effects could result in forming a group of female students with high SQ and male students with low SQ. In this group, an investigation could well come to confusing results, if it intends to demonstrate gender effects without firstly diagnosing the mean SQ of the group.

In this study, it was the intention to keep cultural biases as low as possible, by confining the sample to two culturally comparable schools. However, it would be interesting to do a cross-cultural study in order to investigate the cultural variability of the here presented concepts. Studies of Wakabayashi, Baron-Cohen, Uchiyama, Yoshida and Wheelwright (2007) have shown a cross-cultural stability of the E/S theory, which fits well into their biological framework. Empathizing and systemizing are, following Baron-Cohen, not cognitive styles but biological abilities. A cross-cultural study of the here presented EQ/SQ/SMQ model might well reveal new aspects on these issues. It could particularly show if in other cultures with different science teaching styles, the theoretically predicted negative coupling of the EQ with the SMQ could be found.

Our own data, if the two pilot studies are taken into account, involved students out of some 10 different schools. The results remain remarkably stable. From this point of view, they could, with due caution, be generalized for at least the German speaking part of our country. However, it could again be interesting to explicitly involve schools that differ from our type of school. For
example, in all our schools the average SMQ was rather high, which could again be a possible flaw of the design. Schools with a lower average SMQ could perhaps exhibit different EQ/SQ/SMQ models.

Generally, more research must be done to be able to reliably link our findings to the situation in the real science classroom. Nevertheless, we would like to conclude this article – with due precautions – by outlining some thoughts that emerge from the study as possible implications for school science. Our results seem to point to two main lines of reasoning.

Firstly, as mentioned above, strong systemisers have a high motivation to learn science. In reference to the definition provided by Glynn and colleagues, this is “the internal state that arouses, directs, and sustains students’ behaviour towards achieving certain goals” (Glynn et al., 2007, p. 1090). Good systemisers are not necessarily good at (school) science, but they are more likely to strive for it, which is important for becoming a successful science student. It would be interesting research determining if strong systemisers tend to be good at school science. Our data cannot answer this question.

Secondly, and equally important, empathizers do not necessarily have a low motivation towards (school) science. A very good empathizer can also be a very good systemiser. In this case, s/he can easily show a high motivation to learn science although s/he is a strong empathizer.

The challenge for school science seems to be – at least from this point of view – how to deal with low SQ students, be they good empathizers or not. It could be an interesting research question, how these two groups differ, and how they should be approached to improve the systemizing dimension of their cognitive style, i.e. their drive and ability to analyze the rules underlying a system, in order to predict its behaviour. Our findings suggest that a success in improving the systemizing dimension of these students’ cognitive style could spontaneously lead to an improvement in their motivation to learn science. Research must show if, and to what degree, the
initial level of systemizing can be improved and how this could be done. A biological root of this cognition must not entail that it remains stable over time and inert to education.

A second question that remains unsolved is if it is really true that science teaching does not affect the empathizing cognition of students. Is this a natural trait of science and science education, or is it a flaw of our school science? More than that, could even a positive coupling between EQ and the motivation to learn science be attained? If this were true, then an enormous potential to foster motivation to learn science so far has remained unused. How must science teaching look like in order to meet the empathizing needs of students?

At first glance, the answer seems to be simple: it must involve mental states. But what does that mean? It seems to be too early to give answers to such an important question. It might well be, for example, that involving socio-scientific issues is an approach to it, because they are also subject to economic, social, political and/or ethical considerations as, for example, Sadler (2004) points out. Socio-scientific issues could open the door for dealing with mental states in science education. Generally, “talking science” seems to be a promising aspect of inquiry based science education (Rocard et al., 2007) that may foster the empathizing dimension of students’ cognition, because it always involves the understanding of “mental states” and their adequate apprehension.

Another interesting research project would be to study if there is a relation between our findings and the concept of cultural border crossing, which stems from Aikenhead and colleagues (sf. Aikenhead, 2001). This is a cultural concept that perhaps could be contrasted against the biological concept of the brain type. Aikenhead speaks of so-called potential scientists, who enter the culture of (school) science without problems, and who seem to correspond with the highly systemizing students in our study. Aikenhead estimates that approximately 5% of high school students are potential scientists (personal communication, October 2005), which is comparable to the amount of highly systemizing students in our sample. It is of interest whether the categories
of cultural border crossing could be characterized by the EQ, the SQ. How, for example, do
students belonging to extremal groups on those scales differ in their discourse on science and
science education? It seems appropriate to use a qualitative research method to find out more
about these issues, or else a mixed method approach.

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