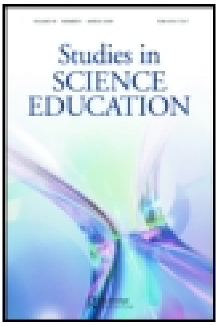

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Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research

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Interest, motivation and attitude towards science and technology at K-12 levels: a systematic review of 12 years of educational research

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The relationship that exists between students and science and technology (S&T) is a complex and important one. If it is positive, then social, economic and environmental consequences are to be expected. Yet, many problems of interest/motivation/attitude (I/M/A) towards S&T have been recorded. A lot of research has been conducted on this topic and a certain number of syntheses have been proposed, but very few of them have followed sufficiently systematic procedures. In this article, we offer a synthetic and systematic description of 228 research articles that were published between 2000 and 2012 and indexed in the ERIC database under I/M/A for S&T at K-12 levels. We focus on the origin of these articles, on the constructs they use and define, on the instruments, and finally on the results they provide, whether correlative or causal. Conclusions and recommendations for future research and interventions are formulated.

Keywords: science education; technology education; literature review; interest; motivation; attitude; K-12

Introduction

A worldwide concern

The connection that exists between students and science and technology (hereafter designated as 'S&T') through the use of such concepts as 'interest', 'motivation' or 'attitude' (hereafter designated as 'interest/motivation/attitude', 'I/M/A') is an important current and ongoing preoccupation and has been a major concern for researchers and educational systems around the world for a very long time (Osborne, Simon, & Collins, 2003). Although students' I/M/A toward S&T is sometimes judged to be generally positive (Awan, Sarwar, Naz, & Noreen, 2011) – though not without some considerable international differences (p. 43), boy/girl differences (Baram-Tsabari & Yarden, 2011) and subject-related differences (Schreiner & Sjoberg, 2004) – the idea that interest in S&T is declining has now been widely accepted. According to the Organisation for Economic Co-operation and Development (OECD) (2006, 2008), S&T professions are less attractive and the share of S&T students in higher education has been decreasing considerably. In 2003, Osborne et al. wrote: 'In […] the past decade, the problem has become even more acute' (2003, p. 1050). Consequently, since 2006, the Programme for International Student Assessment (PISA) has recognised interest as a component of scientific literacy and has incorporated

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interest-evaluating items (8) in its international testing initiative (Krapp & Prenzel, 2011).

Students and school science & technology: a relationship under tension and a need for research-based synthetic knowledge

According to Krapp and Prenzel (2011), besides developmental or identity-based approaches, it is possible to tackle the problem of interest in S&T by supposing that its development depends 'on the quality and type of instruction' (p. 35) that is given to students in schools. But within this hypothesis, the data are not particularly encouraging. For example, Christidou (2011, p. 144), in her review of more than 100 references, argued that 'as they advance from primary to secondary education, students rapidly lose their interest in science and cease seeing it as a viable option for their future, or associating it with their success aspirations'. Likewise, Barmby, Kind, and Jones (2008, p. 1081) have studied the evolution of subconstructs of interest over school years and have concluded that 'the largest decline in pupils' attitudes was for their attitude towards learning science in schools', whereas 'practical work in science' and the 'importance of science' remained relatively unimpaired. In an 'overview of interest research', Krapp and Prenzel (2011, p. 42) pointed out that reports of correlations between achievement and interest are largely inconclusive and that many correlations are not always significant or are rather weak. These authors suggested that 'students with a high cognitive potential for science do not pursue careers as scientists or engineers because they lost their interest during school' (2011, p. 42). Another example of a somewhat problematic relationship between students and science education was given by the 'Science education in Europe: Critical reflections' report (Osborne & Dillon, 2008), which presented an analysis based on the trends in international mathematics and science study (TIMSS) data, where the 'higher the average student achievement, the less positive is their attitude towards science' (p. 14). In the same way, the relevance of science education (ROSE) project recorded that interest was *negatively* correlated with the United Nations comparative national index of human development (Turner & Peck, 2009). Such results seem to suggest that when and where S&T education is the strongest, children generally are (or become) less interested in it.

As suggested by Osborne et al. science thus appears to be 'a love-hate subject that elicits strong feelings in pupils' (2003, p. 1059) and developing interest in the subject therefore appears to be a real challenge as much as it is a challenging research subject. Indeed, in its 2006 report, the OECD expressed regrets that available data-sets did not allow a 'full analysis of the situation' and argued that 'ongoing, long-term studies of student motivation, using specific indicators, should be promoted' (p. 1). Based on such 'discrepancies in findings or insufficiencies of evidence' (Ruthven, 2011, p. 419), other calls for 'research-informed and evidence-based improvement of education' (p. 419) have been made by researchers from the S&T education field.

Nevertheless, even if considerable efforts to synthesise research results have been made in the past 12 years (Awan et al., 2011; Blalock et al., 2008; Christidou, 2011; Foster, 2008; Krapp & Prenzel, 2011; Osborne et al., 2003; Rohaan, Taconis, & Jochems, 2010; Ruthven, 2011), none has given, to our knowledge, enough methodological details (criteria used for the selection of articles, tools and procedures to support analysis, synthesis methods, etc.) to secure objectivity. For example, in some of these review articles it is indicated that 'exemplary findings' were selected for analysis, but without defining what constituted exemplarity. To our knowledge, not one of these reviews was able to provide reliable quantitative portrait elements, such as an appreciation of the proportion of the research effort that was experimental, or the percentage that dealt with one or another of the I/M/A concepts.

Yet we believe there is a crucial need for such a portrait, especially when considering the fact that most existing synthetic initiatives have only concentrated on one concept, such as 'attitude'.

Methods

Methodological choices and research questions

In order to provide an overview of available and convincing research, we have chosen to limit our analysis to recent (an arbitrarily chosen 12-year period) peer-reviewed articles published in research journals. This choice is based on our intention to present results that survived minimal scientific quality testing through systematic and blind reviews that research journals usually provide, as well as to ensure that they were not published by authors other than the ones that belong to the scientific community. We are aware that this choice prevents the inclusion of some interesting insights that are available through reports and books, which sometimes go deeper into analysis, modelisation or argumentation. Nevertheless, we believe that most of the time, the most popular way for researchers to quickly communicate their innovative findings or reflections and to enable their peers to find them easily is through the publication of articles. For reasons of feasibility, we also chose to limit our search to the education resources information centre (ERIC) database, which is by far the most popular and complete indexing system for educational research. This choice unfortunately excludes most articles that were not written in English, but since the use of English is widespread in the research tradition and most researchers for whom English is not their first language nevertheless understand and sometimes write in this language, we chose to make this lesser compromise. (Furthermore, even though we can read French and Arabic, we have not mastered any other main languages, such as Spanish, Italian or Mandarin.)

It is possible that some published and relevant articles were not indexed in ERIC when we conducted our research. These articles unfortunately could not be included.

We have chosen not to limit our selection to articles about 'interest' and so have also included articles that examine 'motivation' and 'attitude' (in S&T). Even if these concepts should not be confounded and have different meanings 'that can clearly be distinguished from one another' (Krapp & Prenzel, 2011, p. 30), they are nevertheless 'neighbouring motivational concepts' (p. 30). Some authors even feel free to jump from one to another, or to go as far as, for example, explicitly suggesting the possibility of using both 'attitude' and 'interest' synonymously. For the purpose of this review, we believe that rejecting one or more of these concepts would not be in the best interest of enlightening the issue and could exclude some very important contributions. We will, however, exclude the concept of 'enjoyment' from our initial selection of articles because enjoyment 'can occur for many reasons, and interest is only one of them' (Krapp & Prenzel, 2011, p. 30). In order to keep this review to a manageable size, we also chose to limit our analysis to articles that deal with science education at the elementary and secondary levels. Since it is often believed that interest is triggered and maintained at an early age, this decision did not seem unreasonable.

In light of these choices, the general research question becomes:

> What do the peer-reviewed articles published in education or S&T education journals between 2000 and 2012 and indexed in the ERIC database teach us about how interest, motivation and attitude toward S&T varies from kindergarten to the end of secondary school (K-12)?

In light of a *post hoc* analysis that revealed the content of the selected articles, and with the intention of providing a more complete overview of the considered literature, we will answer the following sub-questions:

- (Q1) What is the geographic origin of these articles?
- (Q2) What is the general character of the corpus in terms of categories of articles?
- (Q3) What are the main constructs and general definitions that authors refer to in order to address the I/M/A issue?
- (Q4) Which data sources do research articles use to assess I/M/A in research?
- (Q5) What do these articles teach us about the links that exist between I/M/A and other variables?
- (Q6) What do these articles teach us about the best ways to improve I/M/A toward S&T in and out of class?

Procedure

Selection of the articles

In March, April and June 2012, a panel of five specialists participated in several meetings and finally agreed on and validated a way to interrogate the ERIC database and limit compromises in terms of the richness of the corpus. In early June 2012, using the website http://www.eric.ed.gov/, the database was (advanced-) searched for 'peer-reviewed' 'journal articles' 'from 2000 to 2012' (July 26 [final query]) with titles that contained one or more of the three words 'attitude/interest/motivation' *and* one or more S&T words: 'science', 'technology', 'biology', 'physics', 'geology', 'astronomy', 'engineering', 'chemistry' or 'ecology'.[1] A total of 621 articles fell within these criteria.

A second screening phase was conducted using inter-rater agreement involving four specialists. We excluded from the corpus articles that were not published in journals specific to S&T education or to education in general and for which the journal titles had no mention of science (biology, physics, etc.), technology (considered as title keywords), or 'general education' keywords, such as 'learning', 'instruction', or 'teaching'. For example, we excluded articles from *Psychology of Women Quarterly*, *Teaching of Psychology* or *College Student Journal*, but not from the *American Journal of Physics*, *Learning and Instruction*, and obviously not from the *Journal of Research in Science Teaching*. At this stage we also excluded, based on the abstracts and a quick examination of each article, any articles that concerned very young children (preschoolers or very early elementary students), and experiments conducted at the post-secondary level. We also excluded articles that exclusively dealt with teacher training (where teachers' I/M/A in S&T was the main focus instead of students') and articles exclusively about 'technology' when this label was used to designate information and communication technology (ICT) and when there were no signs of S&T. Nine articles were also excluded because they analysed or synthesised previous research and did not offer new insight, even thought they were sometimes extremely pertinent. We will, however, refer often to these texts (Awan et al., 2011; Blalock et al., 2008; Christidou, 2011; Foster, 2008; Krapp & Prenzel, 2011; Osborne et al., 2003; Rohaan et al., 2010; Ruthven, 2011; Toplis, 2011) to frame our research and to compare our results to their conclusions. At the end, this second stage of the selection process, 252 articles were identified for thorough analysis.

We are well aware that during this systematic selection, a few very interesting articles were lost. Some difficult choices were, however, inevitable in order to promote the clarity and objectivity of the process as well as its feasibility.

Development and validation of the grid

An analytic grid was developed, inspired by a grid that was initially used by one of the authors for previous research (Hasni, Bousadra, & Marcos, 2011). It was then validated, pretested and adapted to the present research questions.

The final version of the analytic grid was composed of 36 multiple-choice and open-ended items (with sub-items, for a total of 154 informational columns in the MS Access® software) about the general information of the articles and their content: origin (3), type and scope (5), evoked and defined I/M/A constructs (3), description of the intervention that aimed at developing I/M/A (9), and results (variables, tools used, methodology, new insights into educational knowledge, etc.) (16). (For a full description of the items, see Appendix 2).

Three training sessions were organised to validate the grid and develop a common comprehension of it. First, six specialists individually read the same 10 articles and recorded their analysis of them, and then compared their coding to ensure uniformity of the recordings.

Analysis

In the summer of 2012, 10 educational specialists participated in the full analysis of the 252 articles. An analytic grid was developed by the authors and applied to the material.

The analysts were divided into two teams (which were in continuous communication) that worked together to analyse the corpus and perfect their comprehension of the grid. Each article had at least one codification by one analyst and one verification by another. Most articles were analysed by two people (plus verification) and, with certain exceptions, by more than two (plus verification). Problematic items or articles were brought to other team members and discussed in order to reach an agreement. During this process, the analysts used the same criteria that were presented above (second phase) to disqualify 24 additional articles that could not initially be disqualified by a quick reading of the abstracts and texts (two articles about I/M/A were also disqualified due to unrelated topics, such as interest in the theory of evolution). By the end, 228 articles remained (see Appendix 1 for the full list).

Synthesis and categorisation

From November 2012 to May 2013, a synthesis of the data was conducted. Four people were involved in this operation that, for certain items, involved counting occurrences and, for others, synthesising and grouping qualitative elements into categories based on the research questions. The construction of these categories and subcategories (e.g. the 'results' category was soon split up into 'correlative results' and 'intervention results', the former being further separated into 'collaborative intervention results' and 'inquiry-based results', and so on) was constrained by the frequency with which elements were present (or not) in the articles, and by the weight of the presented results. Indeed, some results were central to certain articles, while others were very indirectly inferred and therefore more precarious. In order to support our decisions, we considered the emphasis that was explicitly given to some results instead of others by the authors. Each of the recordings in the analytical grid was reviewed in light of the developing set of categories (and subcategories), until the entire set of data was treated. We also ensured that each of the articles had a place in the synthesis. Many of the articles also had the potential to fit into more than one category (and sometimes many more). For example, many articles that tested the effects of certain interventions on interest also tested boy/girl differences. When necessary, we allowed such results to fall into both categories (or more). Therefore, the total balance of articles recorded in a group of subcategories does not always correspond to the total number for the entire category. The final set of categories and subcategories, which is presented below, corresponds to the different subtitles of the results section.

Results and interpretations

The results section is subdivided according to the six research questions. Numbers that appear between square brackets '[x]' designate articles that belong to the corpus. They are listed separately from the References section and can be found numbered in Appendix 1. These square brackets identify non-exhaustive prototypical examples. Therefore, many articles are included in compilations, but are not necessarily given as examples. Simple numbers that appear in the text between ordinary parentheses '(x)' signify the number of articles. For example, '(34)' means *thirty-four articles*.

(Q1) What is the geographic origin of the articles?

The articles were geographically associated with the countries where the experiments were conducted or the data were collected. In the vast majority of cases, these locations coincided with the authors' locations. When data from other countries were evoked or analysed in order to make a comparison with the country of origin, only one origin was identified, but when data were collected from more than one country and a co-author from the second country was present, we identified two geographical origins. This happened five times. There were no cases of more than two origins. Table 1 indentifies the origin of the articles by continent and Figure 1 indentifies the origin by country.

It is noteworthy to see that at least 6 out of 10 articles came from North America or Europe, and that among those articles, more than 7 out of 10 were from the US or the UK. The other countries that contributed the most to the issue were Turkey (17), Germany (15), Israel (14), and Australia (11).

Table 1. Provenance of selected articles, by continent.

Region	Number of published papers	Approximate proportion of papers in the database (%)
North America	86	37
Europe	58	25
Middle East	36	16
Asia	32	14
Oceania	12	5
Africa	8	3
South America	0	0

Figure 1. Origin of selected articles, by country.

(Q2) What is the general portrait of the corpus in terms of categories of articles?

Before further discussion about the content of the articles, we believe it is important to provide a general portrait of the corpus in terms of types of articles. We are not referring here to any standardised categorisation, such as the ones that can be found in journals' 'instructions for authors', but rather to a broad categorisation that will provide a general portrait of the corpus. Indeed, since the corpus is already the result of a screening process, classical categorisations cannot apply as well. We identified four major and non-exclusive categories: (a) articles without research results, (b) validation of I/M/A measurement instruments, (c) portraits of students' I/M/A (including statistical descriptions), and (d) effects of interventions on I/M/A (see Table 2).

Table 2. Categories of articles.

Category	Number of published papers	Approximate proportion of papers in the database (%)
Articles without research results	17	6
Validation of I/M/A measurement instruments	12	4
Portraits of students' I/M/A	169	57
Effects of interventions on I/M/A	97	33

Articles without research results

It is noteworthy that 17 articles did not report any research results at all. These articles were mostly presentations or descriptions of partnerships [83;39], contests [164], books [171], training programmes [23], software [203], activities [67;109;122;135;164] or courses about special themes [23;62;82] that were believed to generate I/M/A for S&T and were sometimes justified on the basis of previous research (although sometimes not). The majority of the time, initiatives were described as generating interest, but no systematic data-gathering process was presented to support those claims. Two of these articles also described propositions to better understand class dynamics and to better intervene. One was about multicultural contexts [174] and the other speculated about the effects of different types of teachers on their students' I/M/A [130].

Validation of I/M/A measurement instruments

Twelve articles pursued objectives in which I/M/A measurement tools (all paper-and-pencil) were central, without being necessarily exclusive. New questionnaires [111], or their cultural adaptations [204;207] or simplifications [217] were announced [61] or put to the test (validated) [120;161;225], sometimes in geographically unprecedented contexts [160]. Some validations were made by interviews [214] or calculations of Cronbach's α [204;214]. The results were always positive and always raised arguments that supported the value of the presented or proposed tools. One article was also interested in the positive effect of the personalisation of items [21].

Portraits of students' I/M/A

This category is by far the most quantitatively important one. It can be described as the category in which articles reported results obtained through questionnaires and interviews, but without testing any intervention or pedagogical treatment, as empirical experiments would. These articles could nevertheless suggest causalities, but were mostly interested in perceptions, preferences, differences between groups, psycho-socio-economic variables and interest in particular small-scale objects or events.

In order to give the reader an overview of the different subcategories, Table 3 indentifies the topics that these articles addressed, the number of articles for each topic, and prototypical examples.

We will postpone further description of the results that these articles reported to section Q5.

Table 3. Subcategories of the *portraits of students' I/M/A* category.

Topic	Number of articles	Examples
Boy/girl differences	50	[99]
School-related variables	31	[154]
Decline of I/M/A with age or school year	24	[170]
Performance and self-efficacy	23	[2]
S&T careers	13	[99]
International differences	12	[149]
Sociological variables	8	[155]
Correlations with other variables	8	[224]

Effects of interventions on I/M/A

This category is the second most quantitatively important one of the corpus. It contains articles that described experiments that tested the effects of certain interventions on performance and I/M/A. (We, however, will concentrate on effects on I/M/A). Even if control groups, pretests or appropriate statistical treatments were not always present, there was always at least an assessment of students' interest, motivation or attitude, generally after some intervention. Table 4 provides an overview of the considered subcategories.

We will postpone further description of the results that these articles reported to section Q6.

(Q3) What are the main constructs and general definitions that the authors refer to?

There are three central constructs currently used by the authors that cover the vast majority of interest-like concepts. In most cases, only one of them was given priority in each of the articles, since the authors generally used only one concept or subordinated the others to it. In a few cases, it was not possible to distinguish the main concept from the others. In these few cases, more than one concept was attributed to an article. This explains why the total number of attributions (233) surpasses the number of articles (228). The following sections describe the utilisation of each of the three constructs in the corpus. See Table 5 for numbers of published papers for each construct.

Table 4. Subcategories of the *effects of interventions on I/M/A* category.

Interventions	Number of articles	Examples
Summer camps/competitions/science fairs/field trips	18	[162]
Inquiry- or problem-based learning/hands-on	17	[2]
ICT	10	[65]
Collaborative work	9	[106]
Contextualisation	9	[143]
Science museums	7	[96]
Contact with role models	5	[197]
Gender-specific	6	[88]
Teacher training	3	[206]
Multi-angle massive programmes	2	[141]
Evaluation-based	2	[49]
Other interventions	9	[158]

Table 5. Main studied constructs.

Construct	Number of published papers	Approximate proportion of papers in the database (%)
Interest	63	27
Motivation	49	21
Attitude	121	52

Interest

A total of 63 articles referred to the construct of 'interest'. Of those, 39 articles used it without explicitly providing a definition. What was rather constant was the idea of 'domain specific' [210] preferences [218] or the selection of some subjects [117] at the expense of others [11]. The definitions of interest seemed to be, for the most part, very attached to the 'object of interest'. The main references supporting the use of the interest construct were to Krapp and Hidi's work, which insisted on the 'relationship (generally positive) between individuals and objects' [29;198]. The fact that these references were more recent (from the 1990s and 2000s) might explain why they were less frequent (10). Apart from these, the authors appear to have used the 'interest' construct rather freely. Paradoxically, its definition sometimes included 'motivations' and 'attitudes' [80] as subconstructs. Some definitions even included aspects of emotions and actions [108;128] dear to the 'attitude' construct, as well as 'motives' [210] or 'intrinsic reasons' [218], usually associated with motivation. Interest was also sometimes associated with enjoyment [15;47], while other authors adhered to the PISA 2006 composite definition [30] that includes 'curiosity' and 'willingness'. As with the two other constructs, interest was most often seen as something that drives positive action toward the object of interest, but in this case, and maybe more clearly, it was also sometimes seen as the key factor in career decisions [117].

Motivation

A total of 49 articles referred mainly to the 'motivation' construct. Of those, 20 did not propose an explicit definition of the term. When they did, though, most of the time they included the idea of a 'goal', whether of intrinsic or extrinsic origin [42], that oriented behaviour. However, motivation discourse sometimes seems to have a fondness toward its intrinsic part [219], or is inclined to frequently refer to 'self-sustained' states or processes [129], and not as often to externally driven influences. Often an important element of the proposed definitions was to clearly identify some particular behaviours [9] and goals, which often referred to 'interplays' [205] between values, beliefs [123] or perceptions [53]. As was the case for the 'attitude' construct, 'motivation' often (14) explicitly referred to a strong research tradition associated with Bandura (in the 1970s), who stated that motivation is an 'internal state that arouses, directs, and sustains goal oriented behaviour' [200]. Unlike attitude, very few original definitions were proposed (fewer than 10) and they did not diverge much from the source concept. It is also interesting to note that if 'motivation' was sometimes considered as a subconstruct for attitude, the opposite never occurred.

Attitude

A total of 121 articles used the term 'attitude' as a central concept. Of those, as many as 71 did not propose explicit definitions of it. This does not mean, though, that they lacked implicit adhesion to certain theories. Indeed, in their conceptual framing, they often strongly subscribed to previous work, or used strongly connotative questionnaires. The mere choice of the 'attitude' construct might also have appeared sufficiently transparent for certain authors. Nevertheless, half the time, they neglected to define it.

Many of the 50 remaining articles declared adhesion to the classical construct of attitude, which usually consists of three components (cognitive, affective and behavioural), and the idea of positive or negative (like or dislike) inclinations toward an object. Half of them (26) referred to a definition that completely [32] or partly [146] included these ideas. Of those, 18 referred directly to Koballa's definition [34] as it was formulated in the mid-1980s. Some articles suggested that attitude is a complex construct that contains many subconstructs, among which 'interest, enjoyment, motivation and perceived difficulty' [139] might be included. Others authors incorporated self-efficacy [8], identity [214], utility [70], career aspirations [201], beliefs and feelings [202]. Some articles also defined and reduced 'attitude' according to the instrument they used, like the test of science related attitudes (TOSRA) [192; 208]. Aside from these articles, a rather small number of them (10) suggested original, marginal or composite definitions.

(Q4) Which data sources do research articles use to assess I/M/A in research?

Original research articles usually proceed to assessments of I/M/A. These assessments can have scientific or comparative ambitions. However, they are sometimes rather superficial, gather very few data elements, or pursue very simple and humble goals, like surveying satisfaction only once at the end of a summer camp. In this section, we provide an overview of the data sources and the corresponding instruments (when available) that were used in the selected articles, regardless of their quality or the level of the objectives they pursued. However, articles that exclusively aimed at validating a test and did not use them as data sources have been excluded from this synthesis. Some articles used more than one data source, which explains why the totals do not always equal the sums. Table 6 provides an overview of the data sources.

Answers given by students in questionnaires were by far the most popular data source used to evaluate I/M/A, with an important number that came from tests that were borrowed from previous research (107). Among the most popular of the borrowed tests were the students' motivation toward science learning (6), the TOSRA (6) and the ROSE (5) project test, as well as Pell and Jarvis's attitude scale (6) [16]. What is striking, though, is the variety of tests used in our corpus. Five different tests were used to assess interest, 19 for motivation and 38 distinct ones for attitude. Many homemade tests were also used (74). All of them were said to at least be inspired from other tests or to have borrowed questions from two or more tests. Among them, most were Likert-type (66) [10], and many others were merely made of multiple choice questions. Twelve articles borrowed data from international testing. Only PISA [7;149] and TIMSS [155;156] were used. Data from short surveys or open-ended questions were also published, but rather rarely (8) [178].

Table 6. Data sources used.

Data source		Number of articles	Examples
Questionnaires	Borrowed from previous research (ROSE, SMQ, TOSRA, etc.)	107	[209]
	Homemade but generally inspired from previous research	74	[100]
	Data borrowed from international testing (PISA & TIMSS)	11	[18]
	Open-ended questions & short surveys	8	[215]
	TOTAL for questionnaires	189	
Interviews		16	[102]
Class observations		3	[143]
Other sources (reaction times, questions asked by children on TV shows or websites, etc.)		8	[11]

Sixteen articles recalled the use of interviews, mostly for the purposes of confirmation or exploration, and often with rather small samples [9;102;138] – although some were impressive [169 ($N = 61$)] – or to deal more thoroughly with data previously obtained with questionnaires [75;128]. Qualitative results often revealed students' preferences [169] and perceptions about the effects of certain interventions [35;91].

Class observations were rather rare, with few occurrences, either directly [158: through daily logs] or through video recordings [220], and were mostly anecdotal [191].

Finally, it is interesting to note that there were some rather original ways of using specific data, like using questions that students asked on TV shows [13], magazines [31] or websites [15]. In other cases, students were invited to select books they would be interested in just by reading the titles to see if they would choose a more significant proportion of titles related to the content of some interventions. Their interest in these topics [228] could therefore be inferred. Another interesting source of data included the evaluation of work rates and the number of proposed solutions in the context of real-life (feminine or masculine) tasks called 'artefact design situations' [43]. We believe that these last kinds of efforts to obtain data, which are not necessarily the product of perceptions, are rather interesting, although sometimes demanding.

(Q5) What do these articles teach us about the links that exist between I/M/A and other variables?

This section synthesises research results that were obtained in order to provide portraits of situations about I/M/A toward S&T, without necessarily intervening in them, although sometimes they would also analyse effects of specific interventions on I/M/A (these results appear in Q6). It concentrates on the results obtained with questionnaires or interviews (and sometimes with indirect data, like the questions children asked on TV shows [13] or websites) and frequently on the links that exist between different variables (or different kinds of variables), dimensions (subconstructs), or sometimes simply between different answers. It brings together a very significant proportion of the original and available results of the considered period. Indeed, as many as 166 articles contributed to these portraits, some in many subcategories.

Boy/girl differences

This subcategory is the largest one, with as many as 50 articles contributing to it. Results reveal many interesting but classic invariants, almost leading to a feeling of 'overkill'. For example, most articles that tackled the issue reported very slight or non-significant differences between general I/M/A for boys and girls toward S&T [57;99;126;223], despite the fact that I/M/A for S&T careers was sometimes reported as rather weak [183]. When general differences were recorded, they were mostly at a slight advantage for boys [55;66;226] and, with a few exceptions, recorded at the elementary level [37;176].

Important differences, however, appeared when disciplines were investigated (more than 20 articles addressed such questions). Physics and technology were clearly and universally preferred by boys [29;51;60;101], while a similar preference could be said of chemistry [46], although not as clearly [29;173]. Biology was often preferred by girls [13;29;101;198;222], although some articles reported no significant differences [60;213]. Many other preferences were also investigated but on a smaller scale, like astronomy [119] and earth sciences [87] (both in favour of boys).

It is interesting to see that such differences often appeared more acute as students grew older [16;101] and that social stereotypes were sometimes used to explain disciplinary differences [101;125], especially those concerned with career choices [118].

But deeper differences appeared when the research concentrated on smaller-than-discipline problems or contexts. For example, in biology, cells [198] and extinct species [165] were themes that were preferred by boys, while botany [165], mycology and human–animal relations [14] were preferred by girls. These kinds of results suggest that I/M/A depends more on chosen themes or particular contexts than on disciplines per se, and proposed solutions for a lack of I/M/A often refer to the possibility of adapting problems and study contexts to students' characteristics [47], like when 'feminising' technology was suggested to favour I/M/A in girls [43]. Adapting pedagogical interventions to other boy/girl differences was also often recommended. For example, in some articles boys were described as more 'performance-goal oriented' [26;118;132], and girls as more often driven by social concerns [47]. Girls also sometimes appeared more anxious [26;55]. Boys preferred calculus and conducting experiments, while girls preferred teamwork and written exercises [154].

In light of this very broad summary, it appears possible to suggest that studying I/M/A for S&T (in general) or for particular disciplines would not be as insightful or productive for addressing I/M/A problems as would studying I/M/A for particular themes, disciplinary elements [76] or contexts. This was partially confirmed by a demonstration that some students who were identified as 'least interested in S&T' were in fact *very* interested in some aspects of it [218]. It also appears that studying more fundamental gender characteristics to explain such problems and to intervene is becoming an increasingly popular solution. Therefore, we suggest that our synthesis supports the idea that 'how' S&T is taught might be more important than 'what' is taught. Thus, the origin of the problem of insufficiency of I/M/A might lie in pedagogical considerations.

School-related variables

This is the second most important subcategory with 31 contributing articles. In this section, we will report explicit links that have been established by participants between school-related variables and I/M/A, or statistics links that have been established by researchers between I/M/A and school-related answers or realities. It is important to understand that this section does not provide results of experiments, but rather concentrates on declarations made by students.

Not surprisingly, many articles (7) reported or insisted on the importance of the teacher. Enthusiastic [28;163], encouraging [69] and close-to-their-students [54;192], teachers [120;155] were perceived as factors that were strongly linked to I/M/A. Following teachers came collaborative work in class [28;112;163], followed by what we would label 'meaningful learning', where S&T can be linked to reality [10;30;73;79;108;169]. Students also liked 'hands-on' [153;154], 'inquiry-based' learning [7;28], laboratory experiments [73;139], and learning environments that encouraged independent thinking [144]. Even if they considered S&T as important, they did not seem to like learning about it in the media or books [21]. They also seemed to dislike copying notes, rote learning [79], teaching that overused PowerPoint presentations [28], and written exercises [154], although they preferred traditional exams rather than open evaluation situations [189].

These positive results are interesting and could inspire practices that aim at developing I/M/A, but one has to keep in mind that they are essentially the products of children's declarations, and are therefore difficult to distinguish from desires for comfort, novelty, or simple enjoyment. Since the duty of teachers is not only to favour interest but also to favour learning, the choice of certain approaches should not be a trade-off between the latter and the former. Therefore, we believe that many of the above results should still be confirmed by experiments and that these might benefit from controlling the evolution of learning as well as the evolution of I/M/A.

Decline of positive I/M/A with age (or school year)

Twenty-four articles contributing to this subcategory were interested in the personal evolution of I/M/A for S&T, disciplines, activities in S&T courses and S&T careers, from kindergarten to Grade 12. A considerable number of these articles (16) reported reductions in I/M/A throughout the period (for most studies, by comparing various time spans from 2 to 4 years) [17;21;56;139;154] and especially at the precise moment when the elementary/secondary transition occurred [25;170;185]. This decline appeared stronger for pedagogically traditional [199] and rural contexts [69], and more acute for boys than for girls [46;69;77]. A few discordant articles have reported increases for biology (for example, between grades 4 and 8) [11;12;13], but these were relative increases (compared to other interests) instead of absolute ones, or small increases over very short periods [84].

In some articles that addressed the general issue of decline, calls for reinforcements of early S&T education were sometimes made [127;184].

In summary, according to our corpus, school unfortunately does not seem to be able to preserve the initial strength of students' I/M/A for S&T, especially when we consider instances when distinctions were made between subconstructs such as 'learning science in school' and the 'importance of science' [17], where the former drops more than the latter, or when we consider the distinctive drop of I/M/A between elementary and secondary school. Some authors have therefore argued that the perception that students have of science might in fact be weakened or held back by the perception they have of 'school science' [221].

Performance and self-efficacy

In this subcategory, we included contributions that addressed the links between I/M/A and performance or the perception of performance (self-concept/efficacy), and other closely related variables. Since gifted students are usually good performers, studies about them, or about gifted school-attending students, were included. A total of 23 articles contributed to this category. Ten of these reported connections (and sometimes significant correlations) between I/M/A and performance [147;157;176] or a few with self-concepts [28;40]. However, a small number of studies reported no connection between S&T achievement and perceived satisfaction [144] or 'internal motivation' [56]. Also, students selected to attend high-performing schools did not necessarily appear to have more interest in leisure activities in S&T [192]. As Osborne et al. (2003) pointed out, the relationship between attitude and achievement is a complex one and 'perhaps the most tenable position is that the two are inescapably linked in a complex interaction' (p. 1072). Nevertheless, we believe that the analysis of our corpus suggests that I/M/A and performance (and the perception of such) usually appear to go hand-in-hand.

Some articles interested in the quality or type of I/M/A suggested that learning in 'democratic' [199], 'self-accessed/paced/directed' [151], 'context-oriented' [75] and 'open-ended' [121] pedagogical settings was appreciated by highly performing students.

S&T careers

In our corpus, the link between I/M/A and the choice or intention to pursue studies or careers in S&T was sometimes investigated (13 articles). Not surprisingly, this link was sometimes recorded as positive [45;66].

However, some authors reported a rather low general interest for careers among students [99;182]. Students' choices appeared to be mainly influenced by initial science literacy and school interventions [18], gender and culture [118], family background, self-esteem [58], previous achievements [157] and hobbies or life experiences (especially for technology [9]), but also by the negative perceptions, as Christidou had already suggested (2011, p. 144), that they held of S&T careers. Indeed, these careers were seen as dimly creative (except maybe technology [182]), and not people oriented [131].

Paradoxically, if sometimes young children (grades 1 to 9) expressed less attraction to biology careers [165], biology students later appeared more interested than their physics colleagues in pursuing a career in their field [163].

It could be noted that if counselling journals had been included in our analysis, we might have found more thorough insights about career choices in S&T. Indeed, the choice of a professional path is sometimes a complex personal and psychological process, and it is not a given that science education journals where S&T teaching and learning specialists usually publish will offer the best insight on the matter.

International differences

Articles that belong to this subcategory (12) have international differences as part of their central research questions. It is difficult to propose a unified or synthetic view of the causes of the recorded differences because the authors often explained them by cultural and local differences that were not easy to explain. Why, for instance, would Pakistani students be more interested in S&T careers than English or South-African students? [94] Why would boy/girl differences in I/M/A be less acute in Asian countries? [204]. Even if cultural explanations can be proposed, it might be enough to say, as Awan and colleagues already suggested in a review of international differences (2011), that students from different countries can sometimes show rather important differences in I/M/A and in their preferences [139].

We believe that some of the strongest results might require the analysis of international testing, like the PISA, which included eight items about interest in S&T in its 2006 edition. At least five articles from our corpus were interested in such data [3;18;30;60;149] (analyses of international tests for purposes other than international comparisons [156] are not included here). A noteworthy invariant that emerged from these analyses is that students who come from developed countries express less interest in S&T than the ones from developing countries. To explain these results, we might yield to arguments that invoke that S&T schooling has only recently been made available [11] in developing countries (novelty effects), but it is difficult to overrule the possibility that social desirability could be involved. Indeed, strong schooling (in particular S&T schooling) is often perceived as a good way to be spared from poverty (whether or not this is true).

Sociological variables

Even if many of the articles proposed sociological insights about I/M/A, we believe that eight of them contributed significantly enough to this subcategory to be reported. Three short yet relevant observations can thus be made. (1) It appears that parental education is correlated with attitude (based on TIMSS data [155] and analyses of the mother's education level [192]); although, according to other sources, it does not appear to be correlated with motivation [176]; (2) in the US, white students express more positive I/M/A than some other ethnicities [26;193]; and (3) the link between economic disadvantage and attitude is uncertain, since one article reported that suburban students showed better attitudes than metropolitan ones ([69] based on data from 54 schools), while at the same time students from a very economically disadvantaged school showed better attitudes [211].

Correlations with other variables

Eight articles about the links that exist between I/M/A and other relevant variables provided noteworthy insights that, however, could not be included in the above subcategories. For example, I/M/A appears to be negatively influenced by anxiety

[69;76] and adhesion to creationism [66], and positively by the perceived attitude of peers [69].

Not surprisingly, some attempts at establishing correlations between interest and motivation, for example, were successful [196], but a very interesting result was also reported in Finland, where attitude of the intrinsic kind was reported to correlate with interest, while the extrinsic kind did not [110].

Finally, a most intriguing result was obtained when motivation for S&T was correlated with 'systematising' cognitive style (vs. empathising style). A strong correlation was found with scores obtained on the *science motivation questionnaire* (SMQ) test [223]. The authors argued that 'cognitive styles' might be much better predictors for explaining motivation than gender, and they promised a 'larger and more systematically sampled project' [224: p. 2217].

(Q6) What do these articles teach us about the best ways to improve I/M/A toward S&T in and out of class?

In this section, we present research articles that have in common the presentation of educative interventions with elementary or secondary students in or out of school settings. Although many of them reported the results from comparisons (before/after, and/or with/without intervention), some of them merely reported results obtained with only one questionnaire or survey (although some of them contained questions that referred to temporal improvements of I/M/A [178]).

The articles are subcategorised according to the nature of the interventions. The following subsections therefore give a general overview of the results obtained by the researchers. They will also be commented on for their relative strength.

Summer camps/competitions/science fairs/field trips

In this subsection, we present extracurricular S&T events or experiences that were conducted outside of traditional school settings, although some of them were indirectly linked to school for recruitment or preparation (science fairs). However, all articles about the effects of S&T museums have been excluded. (They are further dealt with in another subsection.)

Most of the articles presented events or experiences but did not necessarily propose comparisons of the effects on I/M/A of such activities with other activities or with their absence. Since most of the activities mentioned in the articles were mainly or exclusively aimed at improving I/M/A for S&T or for S&T careers, and since they were usually free of the typical obligations of government-prescribed school programmes, it is not surprising that most of them had positive outcomes and also produced positive effects on different aspects of I/M/A. In fact, all the considered articles reported improvements, except on rare occasions for some particular subgroups [35] or in some rare cases for some subcomponents of I/M/A, like leisure interest, or career interest [208].

Only one article reported no positive general effects on I/M/A [182], except for the perception of the place of girls in engineering (positive), but it was suggested that such 'unsuccessful' results might sometimes be due to misadaptation of tasks to the level of the students, or to their inability to see the links between S&T and the activity. Sometimes, to explain unsuccessful results, the 'very high' initial I/M/A of students was invoked [35;208]. Indeed, when students go through heavy selection procedures to participate (in activities that go beyond minimal school expectations), one can expect their initial I/M/A to sometimes be rather high and therefore difficult to improve. In other cases, the absence of effect of the considered extracurricular activities on I/M/A was nevertheless judged to be positive, because it shielded I/M/A from the usually observed decrease that can often be seen elsewhere [72;162]. But besides these rather rare 'negative' results, it can be said that the articles that fill our corpus were predominantly enthusiastic about the possibilities of improving I/M/A through extracurricular activities. The following paragraphs will expand on the main categories of extracurricular activities.

Field trips. Three articles about field trips (some very short [166:1 day]) reported positive effects, while sometimes also focusing on the activities that the children recalled (in one case the most recalled activity was identified as a 'hands-on' activity [140]), or on differences between boys and girls (girls being identified as initially more inclined to nature and boys showing the greatest improvement [35]). Only one article established a comparison with a setting where students did not go on a field trip [35].

Competitions. Four articles were about engineering competitions (robotics, electric car construction or science fairs). Two recorded positive effects on I/M/A [208;209], both by comparison with non-participant students. One article did not record substantial improvement and even sadly noticed some crystallisation of certain career stereotypes [182]. Another article concentrated on the motivations that attract students to science fairs and insisted on the importance of self-efficacy [59].

Summer camps. Finally, 10 articles reported studies that were interested in I/M/A in the context of S&T summer camps. These were intensive activities, sometimes away from home, of sometimes considerable duration (six weeks), with specific and explicit agendas and objectives (developing scientific career aptitudes [187], girls' interest in S&T careers [64], using LEGO sets [145]). Most of the research used only post-tests, while others established comparisons with pretests [205] or with data obtained from other research on equivalent students and where no special intervention was made [148].

Overall and not surprisingly, it appears that, aside from a few exceptions, the described extracurricular special interventions almost always ended up with an increase in I/M/A. Suggested comparisons, when available, were usually obtained with control groups composed of students who merely did not benefit from the treatment or who simply took part in regular activities. Therefore, the general impression that emerges from our analysis is that such interventions are generally beneficial for I/M/A, but only in absolute terms. No thorough benefit/cost analyses were provided, nor comparisons with treatments involving 'all things being equal'. The activities that belong to this subcategory involved complex compositions of activities and interventions. They also pursued many goals, and were often intensive, making it difficult to identify the characteristics, duration or elements that explain their success. We thus believe that further research should benefit from concentrating not only on the effects – positive or not – of such activities, but also on the reasons why they sometimes developed I/M/A. In addition, the descriptions of the activities were sometimes rather shallow, making it even more difficult to identify the causes of recorded effects. Such efforts were made in some articles of our corpus, but they were usually limited measurements of students' perceptions. We would also encourage research reports of extracurricular activities with non-selected students, where we believe the best possibility of producing – and recording – gains exists.

Inquiry- or problem-based learning/hands-on learning

Seventeen articles can be considered as bringing original insights to the question of whether or not inquiry- or problem-based learning (as labelled by the authors) has positive effects on I/M/A. 'Hands-on' learning and laboratory work are also included in this category; even though they are not as ambitious about students assuming responsibility and taking charge of solving problems and learning, they can still be considered as closer to inquiry-based learning than 'teacher-centred' approaches. Indeed, they nevertheless involve at least small decisions on the students' part during problem resolution and also sometimes lead to student-driven discoveries. Needless to say, studies in which both students from experimental and control groups took part in 'inquiry-based' treatments and in which other differences were the focus of attention [167] were not included in this section. Articles about after-school inquiry interventions [72] were also excluded.

It is important to know that for many of the contributing articles, the main focus was not I/M/A, but achievement or learning gains. The following synthesis, however, concentrates almost exclusively on the effects on I/M/A.

Among the 17 articles, 11 reported positive effects of tested interventions on I/M/A. It is interesting to note that as many as eight of these articles tested interventions that were identified as 'inquiry-based' or 'problem-based' approaches, whereas only one tested 'tactual and kinesthetic treatments' [136] and two tested 'practical work' [194], although one of them nevertheless involved a 'stimulation of higher thinking' [95]. However, it sometimes appeared difficult to distinguish those positive results from other components of the tested interventions. Indeed, for example, some inquiry-based activities also involved professional scientists [138;215] or collaborative work [190].

Most (5) results were obtained by comparison with control groups. The frequency with which problem-based approaches were conducted in class was also tested and found to be important to produce more of a positive effect on I/M/A [103]. In at least one of these cases, results were recorded positive for boys, but negative for girls [216]. The authors of this article suggested that the 'recurring' uncertainty demonstrated by girls ('[they] wanted to know if they were correct in their setup', p. 233) might be at the origin of the observed differences.

Six articles reported no significant increases in I/M/A (five with control groups). It is interesting to note that four of these were mere 'hands-on' initiatives, with no fundamental problem-based learning or inquiry-based properties [1;8;68;71]. Two of them nevertheless tested 'inquiry-based' interventions [6;146] and reported better learning gains, but also recorded no improvement in I/M/A.

We believe that a rather strong impression that emerges from this review is that most 'inquiry-based' or 'problem-based' interventions have positive effects on students' I/M/A, while most 'hands-on' activities, which do not require as much reflection, do not.

ICT

Ten articles that described the effects of interventions with computers, software, or other technological devices on I/M/A were included in this subcategory. Attempting to synthesise the results that belong to this subsection was not easy because the original purpose of the technology was difficult to differentiate from its pedagogical use and because the recorded effects, when present, were also hard to differentiate from novelty or desirability effects. Nevertheless, improvements in I/M/A have been argued to be generated by some particular educational software (as opposed to none) [104], computer-assisted instruction [65;157;186], the frequent use of web resources [117], and by other pieces of technology (like digital cameras [191], or sensors [36]).

Two articles reported no improvement in I/M/A for *educational entertainment* (edutainment) [104] and decision-making [181] software.

With so few articles and such an important variety of ICT elements, drawing a conclusion was rather difficult. In general, however, it might not be unreasonable to say that ICT has the potential to improve I/M/A, especially if teachers are more knowledgeable of technology (Rohaan et al., 2010). A more thorough analysis, however, of the causes that might explain this apparent potential requires further investigation. As Foster said, 'research needs to be done to assess most of the claims for games for learning effectiveness' (2008).

Collaborative work

In this subcategory of articles, nine research initiatives tested the effects of collaborative (cooperative) interventions on I/M/A, some of them on more specific collaborative models, like 'jigsaw' [22;52], or collaborative 'corrective instruction' [42]. Usually, collaborative learning refers to learners interacting and working together to facilitate acquisition or solving, by sometimes sharing experiences and knowledge, and where individuals depend on and are accountable to one another.

All considered studies included control groups [116]. Eight recorded positive results for students' I/M/A, and one of them involved only gifted students [90]. Some studies had an impressive intervention duration that spanned two months or more [5;177], therefore reducing, we believe, the novelty effects. Interestingly, some studies were compared with 'individualistic' and 'competitive' treatments, whereas 'cooperative' recorded the best results on attitude [5]. Some of these articles hypothesised boy/girl differences, but none recorded any on the improvement of I/M/A [106].

Only one study recorded no general increase on I/M/A for a 'jigsaw cooperative learning' approach on 80 students (half in the control group) over a three-week period, but nevertheless found a significant positive difference for high ability students [52]. One last article reported a comparison between two different cooperative approaches (jigsaw vs. cyclical rotation) and found no fundamental difference on I/M/A [22].

Contextualisation

Nine articles that described the effects on I/M/A of interventions that aimed to bring S&T learning closer to real life or to 'anchor' it to real-life (or realistic) context elements were included in this subcategory. Learning S&T at school has indeed been accused of being too abstract or detached from real-life existence (Krapp & Prenzel, 2011, p. 43), for example, by overusing idealised or mathematical models or concentrating too much on S&T as a body of knowledge and procedures [85]. Contextualisation interventions therefore aim at (paradoxically) reasserting S&T as a human endeavour that attempts to better understand the world students live in and by integrating its social, economic, environmental, (etc.), components. Articles that reported attempts to make S&T more relevant by including themes that students prefer were also included in this subcategory.

All nine articles reported positive effects, but from very different approaches. First, let us consider attempts to contextualise S&T in its social aspects. For example, applying an STS (science/technology/society) curricular approach [4], discussing ethical issues [48], or using case studies of real-life problems [34] were initiatives that appeared to produce positive increases when they were compared to control groups (which often got ordinary 'textbook' treatments [4]), although increases in learning were sometimes not as obvious [48]. Two articles reported increases in I/M/A (by contextualising chemistry in contemporary issues [202] and by involving students in socio-scientific decision-making processes [75]), but this time without contrasting it with a control group [202].

Two other articles reported attempts to interest students by contextualising learning within the professional contexts of crime-solving police stories [78] or authentic genetic laboratory work [114]. This last case had even more success with children that already showed a rather high interest in S&T.

Finally, it appeared that when curriculum design centred on 'topics that seems particularly interesting or useful in their everyday or future lives' [143, p. 19], or on 'activities in which they are interested' (based on previous surveys) [85, p. 704], increases in students' 'physics-related self-concepts' [85] and interesting shifts of motivation toward more intrinsic forms [143] were recorded.

Most authors argued for curriculum designs that aimed at making S&T more relevant to students than it currently is. We believe that the following quote from Haussler and Hoffmann [85] summarises what we have read in many articles that belong to the contextualisation subcategory:

> … students (…) are not little scientists who strive for inquiring the laws of nature for their own sake. Rather, they are interested in physics in the context of its practical applications, its potential to explain natural phenomena, or in the context of chances and risks which lie in physics-based technologies. [85, p. 704]

Science museums

Seven articles were interested in increases in I/M/A that were initiated by visits to S&T museums or centres. These were, however, rather difficult to synthesise, as some of them were mere 'touch-and-go' visits of as little as one hour [96], while others lasted as many as five days [228]. Also, some of them involved highly systematic training programmes [44], while others were free exploration visits [24].

However, all of them recorded an increase in general I/M/A and an interest in S&T careers. In three of them, comparisons with control groups were established [96;137;228]. However, some articles reported disappointing effects of these visits on, for example, anxious girls [96] or the development of the social aspects of S&T [32]. These results, however, are not necessarily discouraging because they were sometimes inferred with validated tools that explored more dimensions than what was tackled in the visits. The authors also sometimes insisted on the importance of pre-visit preparation to ensure that visits to S&T museums were successful and beneficial.

Contact with role models

Five articles contributed to this subcategory. Most of them insisted on the importance of providing role models in order to favour I/M/A and, in most cases, careers in S&T. They included role models in their interventions [115] and sometimes in real laboratories [215]. Four of them targeted young girls in particular and arranged 'female mentoring' [197;210]. All of them reported increases in I/M/A and interest in S&T careers [197], even in male-dominated fields, like technology [210].

Gender-specific

Four articles that addressed the specific problem of girls' I/M/A in S&T were included in this subcategory. Extracurricular mentoring activities, however, were excluded and instead were included in the previous subsection. Even if qualification for this category was based on various considerations (by giving access to girls to specific programmes from which they were previously excluded [201], by adapting specific interventions to compensate for discrimination [86], or simply by intervening in girl-only classes [100]), all four articles pursued objectives that dealt with compensating for the disproportionate lack of interest of girls in S&T. The results appear to support the idea that reducing (and even making disappear) I/M/A differences between boys and girls is quite possible, provided that curricular adaptations [128] or adapted assessment strategies [100] are implemented. Interestingly, if girls are separated from boys, these curricular-driven increases might be even more important [86;100]. It also appears, quite interestingly, that what favours I/M/A for girls also provides increases for boys [86], as was already observed in other reviews (Christidou, 2011, p. 145).

Finally, it appears that when girls are given enough opportunities to develop their self-concept, the decline of their interest can be reduced. Indeed, 'improving the ability of teachers to support girls in the development of a positive physics related self-concept' [86, p. 870] in order to compensate for 'expectations of male and female teachers [that] are, like those of parents, greatly influenced by the traditional sex stereotyping of roles' [86, ibid.] through teacher training has apparently proven to be effective [86]. All recorded efforts to make S&T more 'girl-friendly' have apparently been successful.

Teacher training

Three articles described the effects on students' I/M/A of teacher training interventions that aimed specifically (among other goals) at increasing I/M/A. Teacher training in the context of a National Science Foundation programme reform in Texas appeared to have created measurable increases in attitude toward S&T on African-American fifth-graders [205]. Another six-month training initiative also appeared to have produced positive effects: increased I/M/A not only in students, but in the self-confidence of teachers [97], suggesting that self-confidence might be a prerequisite for student increases. Finally, in an important research study about an intensive and systematic constructivist initiative (called science-PALS) involving an entire school district (and about 90% of its teachers) over a period of three years, positive effects on I/M/A were found to be a function of the number of years a teacher had been trained (for as much as 60 h a year). Meanwhile, no positive results were recorded on learning in that particular study, suggesting that enthusiasm might be easier to change than performance. The authors then argued that pedagogical change requires a lot of time (sometimes years of systematic effort to record significant or lasting changes), that research on the effectiveness of professional teacher training is very demanding, and that solid evidence still needs to be provided.

Multi-angle massive programmes

The previous example of a programme was implemented in an important district and deployed mainly through teacher training. However, sometimes massive programmes also address educational problems from multiple perspectives and through multiple interventions. This was the case for two programmes that have not been described yet in this review. The Australian Science in Schools Research Project (SiSRP) was deployed in order to boost Australians' performance on international testing as well as their attitude toward S&T. It included curricular priorities and support to teaching quality, as well as set performance targets, and improved students' I/M/A. According to a qualitative analysis called 'stories', the programme was a success [74].

Another programme called Scientist 2010 that intervened with children from grades 1 to 12 included a better integration of ICT, regular visits to S&T museums, e-mentoring, etc. It recorded a positive effect on interest compared to a control group [141].

Such 'enriched science curricula' therefore appear, when correctly implemented, to have a positive effect that is sometimes worth the initial investment.

Evaluation-based

Attitude and self-concept are closely linked constructs. Indeed, some authors have even suggested that improving the evaluation process in a S&T context will automatically improve attitude toward S&T as well. In our review, such self-concepts have in two cases been closely linked to the 'philosophy' that underlies the evaluation processes.

In one such study, students were invited to interact in complex ways with content, making predictions, choosing correct statements, etc., in order to 'reveal students' cognitive structures' [113, p. 998], and engage them in learning within an 'alternative' assessment approach. Another article concentrated on the effects of applying a 'formative assessment and detailed feedback' strategy [49, p. 30] that was found to favour interest, reduce anxiety, and increase confidence and participation in learning. The authors argued that 'formative assessment with detailed and supportive feedback seems to be a necessary component of effective science teaching and learning' [48, p. 28]. Not surprisingly, the I/M/A results were positive for both studies when compared with control groups.

Other interventions

A few articles were difficult to categorise because the intervention that was used was insufficiently described or because it was difficult to associate it with previous subcategories. However, some of the interesting results that they provided are presented here in a somewhat telegraphic style:

- The 'cycle of rocks' topic seems to be at the origin of recorded lack of interest of a small sample of Grade 8 students [87].
- A 'brain-based' teaching approach that concentrated on optimal mental states, relaxed alertness, orchestrated immersion, and active processing appears to be 'exceedingly effective' [172, p. 19] for I/M/A, but also for achievement in physics.
- It appears important to overcome disgust triggered by a dissection activity before hoping that it might improve I/M/A [89].
- 'Science kits' are sometimes able to improve I/M/A [93].
- Teaching for conceptual change does not necessarily improve I/M/A [38], although another recent research study has reported the opposite: situational interest might be more powerful than cognitive conflict to favour conceptual change (Kang et al., 2012).
- The systematic use of 'advanced organisers' (charts, text handouts, etc.) appears to support the improvement of motivation [179].
- Some other results that were difficult to qualify according to the articles have also produced increases in I/M/A [95;158].

Discussion

A first comment about the corpus

Through a rather strict selection procedure, we were able to create a corpus which, after analysis, can be considered fairly representative of the research conducted during the considered period. However, the knowledge that this corpus contains can hardly be thought of as representative of all the findings that could enlighten the issue. Indeed, a vast majority of the articles originated from Anglo-Saxon cultures and, even though English is still the language of research, it appears unlikely, considering our answer to question No. 1, that language is not an impediment for non-English-speaking researchers. We had already accepted the limits that came from restricting ourselves to articles because, for example, the best and most thorough insights are sometimes presented at length in books. But another effect of our choices could be the blatant and somewhat suspiciously high number of experimental research articles that reported positive results. There is always the possibility that researchers are more inclined to publish positive than negative or neutral results. However, to explain such a high amount of 'successful' experiments, we can also consider the important number of rather enthusiastic articles that described innovations or activities without systematically testing their effectiveness. We did not find any articles that did not base their choices on previous research, but a surprisingly large number of articles still only had research on their upstream side. We also believe that many articles reported positive results because of the absence of a control group, or because of the banality of what happened in the control group. We did not question the authors' honesty or the competence of their reviewers, but positive results recorded for educational initiatives that were extraordinary and were systematically created and sponsored specifically to improve targeted variables can hardly be, in our opinion, considered as unexpected, nor as insightful, especially if they were conducted in extracurricular contexts with extraordinary resources, and when they addressed difficulties by multiple interventions coming from multiple angles.

We believe that one first conclusion that our review can draw is that when efforts are well targeted and based on reasonably well-documented sources, it is usually possible to increase I/M/A. In short, effort usually produces results. However, we believe that educators who strive to increase students' I/M/A should also be given knowledge that will allow them to professionally select, apply and afterward optimise the most promising interventions, or types of interventions. Thus, we believe that our corpus could possibly inform educators of the absolute value of some interventions, but not necessarily of the ones that have the best benefit/cost ratios, that – all things being equal – are preferable to others, or that ensure that the quality of learning is not threatened. Indeed, we believe that the hypotheses that are formulated in research are sometimes rather comfortable and pose little risk of recording negative results. Of course, they often describe very short interventions, and detecting increases in this context is a real challenge. Therefore, prudent hypotheses might be a reasonable solution to allow researchers to provide results that have the best potential to inform practice. But some of these risk-free interventions can sometimes be complex programmes composed of blends or combinations of many smaller interventions that belong to various categories. For example, collaborative interventions are often simultaneously inquiry-based interventions. If statistical thresholds might in such a case be reached more easily, it would be difficult to attribute the possible positive results to the first, the second, or a combination of both interventions. We therefore encourage research that can inform educators of the possible multiple consequences of the smaller choices they can make, and of the pedagogical 'variables' (more than 'kits', 'programmes', or 'sequences') that they are capable of 'injecting' into their practice, with the available resources and time. If possible, those consequences will be explained by comparisons with the consequences of other treatments, on short as well as long periods of implementations. Some considerable research efforts in this direction have been conducted in the past and are present in our corpus [5;86]. Others have sometimes courageously presented humble but lucid results [180]. But we believe, according to our analysis, that research on I/M/A might benefit from a less enthusiastic research tradition and a more realistic one, which would be founded on the true needs of the educational practitioners and politics.

Comments on variables that drive I/M/A

Another observation that can be made of our corpus is the importance of research that is dedicated to boy/girl differences. We believe that our corpus does not allow us to clearly affirm that girls are less interested in S&T than boys. Where differences become clearly observable, though, is in certain disciplines, like physics and technology, and moreover with certain topics, themes, particular problems or ways of tackling them. Thus, when considering smaller objects of interest, new differences appear between the sexes and between individuals. This could suggest that it might be more productive to address the problem of I/M/A with girls, but also with all students, on a smaller-than-disciplinary scale, by considering the sum of day-to-day pedagogical interventions that are typical of a topic, or a discipline, and that make up the relation that exists between children and certain categories of problems, disciplines or S&T as a whole. It is not impossible, for example, that the pedagogy that is traditionally used in physics teaching might possess distinctive features that would explain why some students are less interested in it. In this perspective, a recent study (Swarat, Ortony, & Revelle, 2012) has gone as far as demonstrating that the 'form of the activity rather than content topic and learning goals decides for the interestingness of an instructional episode' (p. 515).

A third observation that can be inferred from our data is that I/M/A in S&T appears to clearly decline with school years. It is unclear if this decline can be attributed to school itself (as opposed to maturation), but many clues still point in this direction. First, the abrupt reduction recorded by many observers (Christidou, 2011, p. 144) between elementary and secondary courses can support this analysis. Indeed, while it remains possible to attribute this phenomenon to developmental variables, the important differences that exist between elementary and secondary school functioning might explain the tumble. Second, we believe that PISA analyses that recorded negative correlations between interest and S&T performance also explain the decline. Indeed, where schools are best equipped to favour performance and where students have the most contact with S&T, the subject fails to interest them (Awan et al., 2011, p. 48; Krapp & Prenzel, 2011, p. 41; Mullis et al., 2008). Third, many students' declarations in surveys support the idea that there might be a big gap between what school concentrates on or offers and children's preferences. Finally, the important rupture and divergent evolution that seems to exist between 'S&T at school' and 'interest in S&T' variables [17;85] also seems to confirm this (Barmby et al., 2008, p. 1085). All of these observations raise many questions about what is happening in schools, what kind and quality of instruction is being given, the goals that instruction pursues, and the enthusiasm it is capable of raising (Barmby et al., 2008, p. 1090). The question of whether students become uninterested in school as a whole or uninterested in S&T in particular is also to be resolved. In school years, particularly at the secondary level, students are often invited rather early on and repeatedly to think about their career possibilities, in order to eventually make a knowledgeable decision. If they respond positively to this invitation, it should not be surprising that, except for the field or career they eventually choose, all other possibilities should show declines.

A fourth observation that can be made is the close link that seems to exist between self-efficacy and declared interest. Since S&T is often perceived as a field destined to attract high achievers, it appears that the students who intend to pursue S&T studies and eventually a career in the field are not the ones that express the best I/M/A in S&T, but rather the ones who have good self-esteem or perceive themselves as being good achievers. In short, those who feel they can, go into the field. Therefore, it appears important, just as Barmby et al. (2008, p. 1087) argued, to preserve and develop children's feelings of self-efficacy in S&T courses if we want them to eventually consider studies or careers in S&T. We do not believe that negotiating expectations downwards is a viable solution, but it might be interesting to consider less elitist and more supportive approaches in the teaching of S&T. Perceptions expressed in questionnaires point in that direction as well. Also, it appears that if children are interested in S&T early in their lives, their I/M/A is less likely to fall rapidly. Thus early interventions, as Osborne et al. suggested (2003, p. 1072), appear to be appropriate.

Comments on research

Another observation that can be made concerns the instruments that are used to assess I/M/A, namely the almost generalised use of questionnaires. These kinds of tools provide obvious benefits. They are easy to use, appear to be quite statistically reliable, and allow quantitative comparisons and the possibility of following evolutions of I/M/A. However, they are obviously limited to perceptions. It is not irrelevant to consider perceptions in issues that have such clear psychological components as I/M/A, but the mind is a tricky thing that has been shown to sometimes trick itself. The use of questionnaires is so common that it is not impossible that researchers have somehow lost sight of its limitations, in ways that are suspected (like for novelty or social desirability effects) but also in ways that are not necessarily known. Of course, if presumptions of honesty exist and simple questions like 'Are you interested in S&T?' are asked, there is no reason to have doubts about the relative merits of the answer. But there are instances where interest and enjoyment (pleasantness), for example, have been known to diverge, as in the appreciation of works of art or pictures (Renninger & Hidi, 2011, p. 172). In fact, we have to acknowledge that perception questionnaires are not 'tasks' in the strict sense of the term. The concept of a 'task' suggests difficulty, or a challenge. Thus, it is not impossible that authentic tasks that challenge students' I/M/A would provide different results than declared perceptions. In our corpus, we recorded at least two instances where efforts to propose authentic tasks were made [43;228]. We believe that these kinds of efforts should be encouraged. As for the questionnaires that the articles have described and used for research, we can only regret the very large number of them that were used or developed. After examining most of them, we conclude that they are often quite redundant, and in many cases the reason why new tools have been proposed and validated eludes us. Many questionnaires ask essentially the same questions, but in forms that are dimly divergent, so that they pursue the same goals, while simultaneously forbidding comparisons from one article to the next. Sometimes, adaptations based on language or cultural or curricular differences appear justified, but this is not the case with most developments. On the contrary, the widespread use of some tools provides new possibilities, like the 2006 PISA test did. We therefore encourage researchers to consider using items or instruments that are already available, like the SMQ2, the TOSRA, or others, thus allowing interesting comparisons between student profiles, countries, interventions, durations, etc. In this context, each new research study would add a brick to the building instead of merely contributing through reinvention. We also believe that the generalised use of a smaller number of instruments, even if it might sometimes involve compromises, would probably benefit the community of researchers, if it aimed at developing discussions, mutual comprehension and a sense of belonging to the community.

Finally, we noticed that most articles described research efforts that were deployed over rather short periods of time, or that used transversal designs instead of longitudinal ones. Since we believe, as Hidi and Renninger suggested, that individual interest has to be distinguished from (and depends on) situational interest (2006), then the development of interest should benefit from being considered as a long-term affair and more longitudinal research efforts should be made.

Conclusion

In this review, we strove to provide the most reliable portrait possible of an important cross-section of the original research articles that were published in the first years of the century. In order to secure this reliability, we explained the process by which we selected and analysed the articles. Among other things, we discovered that an overwhelming majority of the ones that were indexed in ERIC originated from the US and the UK, and that most articles used attitude as a central concept. We also noticed that even though the tools (like questionnaires) they used were borrowed, no particular tool imposed itself as the leading one, and in consequence many projects may have felt the need to adapt or develop their own. We also saw that very few research efforts went beyond the use of questionnaires.

Our analysis revealed that boy/girl differences were studied very frequently and that gender preferences were not as often linked to scientific disciplines as they were to pedagogical contexts, or smaller-than-discipline content objects. We also saw that declines in I/M/A were linked to many variables, including self-efficacy, and that cumulated positive experiences in S&T might prevent such declines, like summer camps and other out-of-school experiences, but also within schools, where all sorts of initiatives could be intensified. For example, inquiry-based (and not just 'hands-on') learning has been quite convincingly argued to favour I/M/A. This is in line with other synthetic research that has already argued that it might trigger positive effects (Christidou, 2011), but is also in line with other very convincing original research papers that did not originally appear in the initial selection (Akinoglu & Tandogan, 2007). Good contextualisation of content to be taught also appears to be important in order to get students interested. However, this pedagogical intention (linking content with real-world issues, real phenomena or needs) has already been suggested repeatedly in related literature (Christidou, 2011; Hulleman & Harackiewicz, 2009; Renninger & Hidi, 2011; Venturini, 2004), and is somewhat self-evident. Indeed, S&T exists for the exact purpose of explaining the world and increasing well-being. It might therefore appear paradoxical to remind teachers of the importance of rebuilding links between S&T and reality. Nevertheless, this recommendation is judged to be important to repeat. It also suggests that studying the reasons why (and how) science is getting distorted when taught in elementary and secondary classes might be most insightful. Our analysis also suggests that collaborative work, contact with real scientists and novelty (Renninger & Hidi, 2011) should not be neglected. Overall, as Christidou (2011) suggested, it appears that the general quality of teaching is never brought into question and is considered as being central to the development of I/M/A.

We hope that in the future, reviews such as ours will update our understanding of I/M/A in S&T phenomena and the research efforts that study it. Our very broad review has convinced us that the next steps could be (1) to deepen our understanding of some of the most ambiguous or controversial results, like the causes of the decline of interest; (2) to confirm the most promising ones, like the effects of inquiry-based pedagogical designs; or (3) to look deeper into places that, for all sorts of reasons, research has not paid much attention to, like assessments of interest that would not be obtained by other means such as opinion questionnaires, or like negative factors that are likely to discourage students from S&T, and not only the ones that favour I/M/A, etc.

Unfortunately, our review of literature does not lead, we believe, to a great number of outstanding discoveries. By re-reading other synthetic articles, like Venturini's (2004) for earlier periods, we find many similar results and recommendations. However, we believe that by providing arguments that emphasise or insist on the importance of some particular 'candidate' factors, we are contributing to the debate for the best ways to address the current and unfortunate disaffection. We also believe that researchers might benefit from our 'as-reliable-as-possible' review in order to position, orientate and therefore optimise their energy in the context of a collective effort by the international community to enhance our knowledge about I/M/A and, in turn, interest our youth in the sciences and technology in the long term.

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Note

1. (Title: interest* or Title: motivation* or Title: attitude*) and (Title: science* or Title: biolog* or Title: technolog* or Title: physics or Title: chemistr* or Title: geolog* or Title: astronom* or Title: engineer* or Title: ecolog*) and (Publication Type: 'Journal Articles') and (Peer Reviewed/PublicationDate:2000–2012). Asterisks were used to allow some disciplines like 'Microbiology' or 'Biophysics' to be included and in order to avoid rejection of different declinations of some important words, like 'motivationAL' or 'astronomicAL'. Also, note that 'physics' was searched without an asterisk to avoid article titles about, for example, 'physical education' or 'physician', which refer to the practice of medicine.

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Appendix 1. List of the 228 selected articles

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Appendix 2. Analysis grid

A. Paper information

1. Reference
2. Authors' institution of origin
3. Places where the research was carried out
4. *Type of paper analysed* (only peer-reviewed articles were consigned using this grid)
5. Category of paper

   (a) Results of an empirical research
   (b) State of previous research (synthesis, meta-analysis)
   (c) Results of a documentary analysis
   (d) Critical stand

(e) Intervention proposal
(f) Training proposal
(g) Other (specify)

6. *School grades taken into consideration* (only papers that considered at least primary or secondary level were taken into account)

   (a) Specify, if available, the experimental subjects' grade or age

7. Sciences and technology fields taken into consideration

   (a) The study concerns sciences and technology in general
   (b) Biology
   (c) Physics
   (d) Chemistry
   (e) Geology
   (f) Technology
   (g) Astronomy
   (h) Mathematics
   (i) Other (specify)

8. Personal comments from the reader on this section

B. Concepts' description

9a. *Is the key concept that appears in the title or descriptor interest, motivation, or attitude?* If it's another, specify.
9b. *Is that key concept explicitly defined, defined throughout the text or not defined?* How is it defined (dimensions, attributes, and indicators) and who are the authors cited in this definition?
10. Is there a definition of the other principal concepts directly associated to the key concept, and who are the authors cited in this definition?

C. Procedures and interventions proposals to favor interest

11. *Is there a proposal for an intervention with the students?* If no, go to section D.
12. *Is the intervention targeted to primary or secondary grade students, or to another school grade?* Specify, if possible.
13. *Is the intervention taking place in school, whether in or out of class, or out of school?* Specify, if possible.
14. *Is the intervention taking place during S&T classes, in another class, or elsewhere?* Specify, if possible.
15. *Are the main players taking charge of the intervention teachers, other school professionals, parents, actors of S&T promotion, researchers, or other players?* Specify, if needed.
16. *Short description of the intervention* (if there is one).
17. *How do the authors justify this type of intervention?* Specify if this justification is based on research data or not.
18. What are the limitations to this kind of intervention that the authors mention?
19. Personal comments from the reader on the intervention proposal.

D. Information on the research's methodological aspects

20. *Are there a methodology and results in the paper?* If no, go to section E.
21. Are the research's objective(s), question(s) or hypothesis(s) stated explicitly, stated throughout the text or not stated?

22. *Which are they?* Copy and paste the question(s) or objective(s).
23. Indication of the dependent variables related to the research questions and the key concept (interest, motivation, attitude, etc.)

    (a) Not mentioned
    (b) For S&T in general
    (c) For S&T in school
    (d) For specific fields or knowledge
    (e) For studies in S&T
    (f) For careers related to S&T
    (g) Other

24. If needed, specify the other dependent variables.
25. Indication of the independent variables related to the research questions and the key concept (interest, motivation, attitude, etc.)

    (a) Not mentioned
    (b) Age and school grade
    (c) Gender
    (d) Social environment
    (e) School environment
    (f) Prescribed curriculum
    (g) Taught curriculum (school intervention)
    (h) Intervention taking place outside school (but related to school children)
    (i) Other

26. If needed, specify the other independent variables.
27a. Is the sample used specified?
27b. If yes, describe it briefly.
28. *Process used for data collection* (indicate if the tool is available)

    (a) Questionnaire
    (b) Interview
    (c) Direct observation in class
    (d) Video recording
    (e) Audio recording
    (f) Analysis grid
    (g) Not specified
    (h) Other (specify)

    Specifications:
29. Was the process used for data analysis a qualitative analysis, a quantitative analysis, a mixed analysis (if specified by the authors), not specified, or another type of analysis (specify)?

    (a) Clarify the procedure for data treatment if necessary.

30. Is the connection between the methodology and the objectives consistent, or does it present minor or major deficiencies (reader's reasoned personal judgment)?
31. Reader's personal comments (e.g. remarks on objectives, data collection, data analysis, etc.).
32. What are the main results related to the questions or objectives mentioned and based on research data (for each objective, describe briefly the main results)?

33. Are the results obtained strong, average or weak (reasoned personal judgment)?
34. Reader's personal comments on the results' strength.

E. General remarks

35. *Identify the Chair's objective(s) that is (are) related to the contribution of this paper*. Specify when the contribution is exceptional.
36. Authors' relevant recommendations.