Results in the International Mathematical Olympiad (IMO) as Indicators of the Intellectual Classes' Cognitive-Ability Level

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1 The International Mathematical Olympiad

The International Mathematical Olympiad (IMO) is a competition for persons below age 20 who are usually students but not yet studying at university. Countries select six individuals in within-country competitions (normally National Mathematical Olympiads) to participate in the IMO. Each participants' task in the IMO is to individually solve six mathematical problems. The IMO is held annually in a different host country. Problems should cover topics not taught at school and range from geometry and number theory to functional equations.

Countries prepare their participants in training camps similar to those for Olympic Games. The first IMO was organized in 1959 by Rumania; from 1960 until 1975, the IMO was held in former socialist Eastern European countries, and since 1979, it has usually been held in Western countries or in developing nations. About half of all participants receive a medal; around 8% receive a gold medal, 16% a silver medal, and 26% a bronze medal. Countries are ranked by scores; in the last several years (with the exception of Russia in 2007 and Bulgaria in 2003), China normally won the IMO.

Females are underrepresented in the IMO (around 10% or lower, depending on the country), but this is to be expected given the differences between women and men in high-ability mathematics studies. For example, on the Scholastic Assessment Test (SAT)-math[1], the female-male ratio is 1:6 among the best 0.01% (SAT score ≥ 700; Wai, Cacchio, Putallaz, & Makel, 2010). Mean differences in the average math level between women and men also favor men (important exceptions are in Arabian and Muslim countries, where girls generally achieve better results than boys in student assessment studies; e.g., Trends in International Mathematics and Science Study, or TIMSS[2], 2007; see also Mullis et al., 2008, p. 58f.). Researchers disagree on the reason for this disparity, with theories usually centering on the nature vs. nurture debate (Ceci & Williams, 2010). The fact that gender differences at the top math percentiles have been decreasing in the last decades underscores the potential of social and cultural factors.

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[1] Formerly the Scholastic Aptitude Test and now the Scholastic Assessment Test, the SAT is a multidimensional cognitive-ability test that includes mathematics and verbal scales. The SAT is used in the United States for college admissions. (The terms "ability" and "competence" are interchangeably used in this text.)

[2] The 1995 Third International Mathematics and Science Study, now known as the Trends in International Mathematics and Science Study, is a multidimensional cognitive-competence test measuring curriculum-oriented knowledge and ability in mathematics and science of 4th or 8th graders, repeated every 4 years.

Research also shows that IMO participants are usually from households with parents of above-average educational and job levels (and therefore above-average income) and intact families with two parents (Heller, 2008; Heller & Lengfelder, 2010; Wagner & Neber, 2007). Later, as working adults, they regularly have academic occupations and, as scientists, above-average numbers of publications and patents, but – similar to other academics – fewer are married (and therefore are likely to have fewer children). The parental influence is not astonishing, considering that cognitive and personality development depend on genes and environment, the latter ranging from intellectual stimulation, education, reading, the available number of books, parenting style, completeness of family, and school quality to financial means invested in education. Within the United States Olympic teams (Math, Physics, and Chemistry), Asians are overrepresented (Asian Americans compose 24.0% of the teams) and Africans are underrepresented (African American compose 0.3%; Campbell & Walberg, 2011). The same pattern of results is found if nations and cultures are compared. Generally, even small differences in means lead to large frequency differences in the ends of statistical ranges, the tails of test results (Hunt, 1995). Many former Olympiad participants go on to outstanding achievements in science (according to Campbell & Walberg, 2011, 52% of the U.S. Olympians earned doctorates, and more than a half studied at prestigious universities, such as Harvard, Massachusetts Institute of Technology, Princeton, Berkley, and Stanford). Some of the benefits they experience may be attributable to former and continuous parental support, but the positive experience of participation in the IMO – the preparation for the Olympiad and the signaling of high competence by having been participants – could have also been a factor in improving their careers. But what relevance do IMO participants have for society?

2 Cognitive-ability theory of wealth

Human-capital theory claims that economic outcomes are crucially dependent on the attributes of individuals (Becker, 1964/1993; Mincer, 1958; Schultz, 1961; see overview by Ammermüller & Lauer, 2007). First developed by economists for analyzing individual success in the labor market, this theory was also adapted for analyzing the development of nations: Attributes of individuals within a society are relevant for the economic success of a country. Theoretically problematic is the diffuse psychological concept of human capital (see Rindermann & Thompson, 2011): What within “human capital” is relevant for job performance? At a closer look, two main attributes can be distinguished: Cognitive ability (also known as cognitive competence) and discipline (including self-discipline). *Cognitive ability* comprises the ability to think (intelligence), the store of true and relevant knowledge, and the intelligent use of this knowledge. *Industrious discipline* (diligence, commitment, conscientiousness, self-discipline, self-monitoring, agreeableness, robustness, and assertiveness) stands for motivational and personality attributes relevant for work. At both the individual level (Schmidt & Hunter, 1998) and the country level (e.g., Rindermann & Ceci, 2009), cognitive ability is more important than other attributes. Additional physical attributes (e.g., health, eyesight, hearing ability), personality traits and attitudes (e.g., agreeableness, ethical orientations), and competences (e.g., social competence) are relevant in the working process, but less so for explaining individual or national differences.

A vast amount of work done by different researchers and stemming from different research paradigms shows that cognitive ability strongly contributes to a nation's wealth (Hanushek & Woessmann, 2011; Hunt & Wittmann, 2008; Jones & Schneider, 2006; Lynn & Vanhanen, 2006; Rindermann, 2008a; Weede, 2008). Economists, sociologists, psychologists, and political scientists agree that cognitive ability contributes to wealth and to its growth. Other terms (e.g., competence, achievement, education, cognitive skills) are used interchangeably. But using the term *education* to refer merely to educational degree is misleading; mere education without ability effects lowers growth and wealth because education as a process consumes time and all other forms of investment, which therefore cannot be spent on production (see Rindermann, 2008b, Fig. 9). Only education as a proxy for ability (mainly cognitive ability; Frietsch & Grupp, 2007) is relevant for wealth. Does ability at different levels have the same effect?

3 The intellectual-class hypothesis: the relevance of the gifted for technological progress and managing complexity

According to the *intellectual-class hypothesis*, the group in a society with the highest cognitive competence – the gifted – should have the largest positive effect on affluence. Several authors have described this phenomenon implicitly or explicitly. For example, Florida (2002) speaks of a "creative class", Gelade (2008) discusses "elite group size", La Griffe du Lion (2002) describes "smart fraction theory", Hanushek and Woessmann (2009) call the cognitive elite "rocket scientists", Pritchett and Viarengo (2009) speak of "global performers" and Weiss (2009) refers to the "smart fraction". As opposed to other forms of capital, the law of diminishing returns seems not to be valid for cognitive competence: The higher the cognitive ability and the more persons at higher cognitive levels, even at the highest ability strata, the better and with no decreasing effects. Following research at the level of individual differences (Park, Lubinski & Benbow, 2008), even among the top 1% of cognitively competent persons, the upper quartile (rank 99.75) unambiguously outperformed the lower quartile (rank 99.25) in scientific and technological achievements like science, technology, engineering, and math (STEM) publications and patents.

At the level of societies, this group has three important effects: first, it stimulates, develops, and transforms *innovation*, which is crucial in a modern economy for success at markets; second, it helps to manage *complexity* in a world of growing technological and organizational challenges (in production, financial markets, science and society, of tasks in everyday life and work); and finally it contributes to the development of *economic systems*, *politics*, and *culture* in a more effective, complex, free, and (usually) more humane direction. Innovation (Schumpeter, 1911/1983) includes new products, methods of production, markets, suppliers, and organization, as well as their adaptation to local circumstances. Thus, the process of innovation comprises not only the work of scientists and engineers, but also of entrepreneurs, administrators, managers, jurists, and politicians. These assumptions are backed by results from two former studies, both of which found that the high-cognitive-ability group showed a strong influence on intellectual excellence in STEM-related fields and positively influenced economic freedom (Rindermann, Sailer, & Thompson, 2009; Rindermann & Thompson, 2011).

4 Results in the International Mathematical Olympiad as an indicator of the cognitive ability of a nation's intellectual class

Usually the levels or the sizes of intellectual classes are measured by the results of student assessment studies, such as TIMSS, PISA, and PIRLS.[3] Compared with estimations of levels or sizes based on mean IQ results, the advantage of using means from student assessment scores (SASs) is obvious: The data are empirical, not calculated. Because of different homogeneity of societies and the existence of important subgroups (e.g., United States vs. Finland, Israel vs. Japan, Singapore vs. Hong Kong) mean level and high-ability level or fraction size above a certain threshold differ. Psychometric IQ data have also been criticized (e.g., Hunt, 2011), but correlations between IQ and SAS means are very high (Rindermann, 2007). TIMSS, PISA, and PIRLS are mainly administered in developed regions, and important nations, such as India, China, and many countries in Africa, are missing (in China, only the city of Shanghai participated in PISA 2009). Also, results are biased by school attendance rates and age. Single results, such as those for Kazakhstan (divergent results in TIMSS 2007, 4th graders, vs. results similar to neighboring countries in PISA 2009), could be outliers. But the country-ranked results from the IMO (available at http://w.imo-official.org/results.aspx) cover 110 countries, including China, India, Pakistan, some sub-Saharan African countries (e.g., Mozambique, Benin, Nigeria, and Côte d'Ivoire), and also smaller countries from Latin America (e.g., Cuba, Panama, and El Salvador). Additionally, data stem from different

[3] Since 2000, PISA has been repeated every 3 years to measure the cognitive competences (literacy) of 15-year-old students in reading, mathematics, and science.

PIRLS (Progress in International Reading Literacy Study) has been repeated every 5 years since 2001 to measure the cognitive competence (literacy) of 4th graders in reading.

decades, from older students (closer to adulthood) and in a for science and technology important domain: mathematics.

However, before using IMO data as indicators for the cognitive level of intellectual classes, several problems have to be solved:

(1) First of all, we are not interested in the level of the six IMO students as individual math prodigies, but as an indicator of the ability level of the intellectual class in a country. This level is correlated with the mean level but the construct is high ability, in the more narrow sense the ability level of the top 1‰ to 0.0001‰ (in the United States, IMO: top 0.0008‰, in China 0.0002‰; translated in the IQ metric assuming a mean IQ of 100, this equals an IQ of 140-180; Campbell & Walberg, 2011, p. 9) of current youth in mathematics. This information is used as an indicator of the ability level of a more general intellectual class (around the top 1% to 5% of a society) in the age of the workforce (between 20 and 60) and not only in mathematics, but also in general cognitive abilities (with a focus on STEM achievements).

(2) The second problem that has to be examined is that nations are differently large. China comprises around 1.33 billion people, India 1.21 billion, and the United States 308 million, but Finland has only 5.37 million, Bulgaria 7.35 million, and Singapore 3.2 million (not counting foreigners). Therefore, countries draw their math prodigies from differently large samples (Wagner & Neber, 2007). Thus, larger countries should have more top gifted students than smaller countries, and if only the top six students have to be chosen, their ability level should be higher. In fact, for this reason, large countries are advantaged; China is normally leading, then come Russia and the United States. Depending on the research question, this aspect could be useful or not: If we wanted to know which nations in the future will produce the Fields Medal or Nobel Prize Award winners (ceteris paribus), the successful students at leading U. S. universities, and the ordinary scientists, these numbers are informative.[4] But if the results are used as an indicator of the cognitive-ability level of the intellectual class of a country, a correction for population size is necessary (in the best case, using only the number of persons below age 20). If simple division were done by population size (independent of age cohort), small countries would be leading (first Liechtenstein, then Iceland, Macao, Luxembourg, Cyprus, Estonia, Macedonia, Mongolia, Latvia, Singapore, etc.), and a country with

[4] However, the relevance of ethnic-intellectual minorities, such as the Jews or East Asians in the United States or the Jews in Europe and other parts of the world, will be underestimated (e.g., Zuckerman, 1977/1996, p. 68ff.). For instance, in 1982, Grigori J. Perelman won a gold medal with a perfect score as a member of the Russian IMO team.

excellent results, but a large population (such as China) would be at the third last position.

One aspect of this overcorrection problem lies in the limited range of results: Only country ranks based on medals are reported for each Olympiad. And a country such as China could not be better than the first rank. It would be necessary to have results at a conventional psychometric measurement scale, such as SAS or IQ tests. The second part of the overcorrection problem lies in the nonlinear growth of intellectual-class competence with population size. In two samples with the same mean ability and standard deviation (IQ: M = 100, SD = 15), among 10 persons, 1 (the highest/best) will have an IQ of 119; among 100 persons, 1 will have an IQ of 135; among 1,000 persons, 1 will have an IQ of 146; among 10,000, persons, one will have an IQ of 156; and among 100,000 persons, 1 will have an IQ of 164. In other words, the larger the sample, the smaller the increase in ability. Additionally, in smaller countries, the selection and training procedures could be more severe (a kind of David-against-Goliath effect). Thus, a correction of population size is necessary – we chose to divide the positively inverted mean rank by the fourth root of population size (a somewhat arbitrary formula).

(3) The third problem relates to communism. Nations with a communist background seem to be advantaged. The cognitive Olympics were invented in communist countries (as were sporting competitions: "Spartakiads") and therefore have stronger roots in these countries (Wagner & Neber, 2007, p. 224). Preparation for the Olympiads is probably more intense and extensive in such countries.

(4) The final problem is that, from 1959 to 2010, the number of participating countries increased from decade to decade continuously, from around 10 in the 1960s, 20 in the 1970s, and 40 in the 1980s, to 70 in the 1990s, and from 90 to 104 in the first decade of the 21st century. But to be the 10th among ten countries is different than being the 10th among 50 countries. Thus, it is necessary to use a *relative rank* (R) position (rank, r, relative to the absolute number, n, of participating countries: $R = \frac{(n+1)-r}{n}$. This relative rank (R) was finally divided by the fourth root of population size (*pop*), *relative rank relative population size: Rpop*= $\frac{(n+1)-r}{n} \times \frac{1}{\sqrt[4]{pop}}$.

Table 1a. Overview of country values (IMO measures)

	IMO scores (relative rank)						**IMO scores (relative rank and population size)**					
Country	**M 91-10**	**2001-2010**	**1991-2000**	**1981-1990**	**1971-1980**	**1959-1970**	**M 91-10**	**2001-2010**	**1991-2000**	**1981-1990**	**1971-1980**	**1959-1970**
	scale from 0 to 1, relative ranks						≈ IQ-scale (M=100, SD=15)					
Albania	.20	.26	.13	-	-	-	136	138	134	-	-	-
Algeria	.02 -	.01 -	.03 -	.20	.05 -	-	126 -	126 -	128 -	134	135 -	-
Argentina	.60	.62	.57	.21	-	-	143	142	143	134	-	-
Armenia	.53	.45	.61	-	-	-	152	147	157 +	-	-	-
Australia	.77	.75	.78	.57	-	-	151	149	153	148	-	-
Austria	.49	.44	.54	.63	.61	.21	146	143	149	155 +	157 +	144
Azerbaijan	.36	.47	.25	-	-	-	140	144	137	-	-	-
Bahrain	.04 -	-	.04 -	.28	-	-	129	-	131 -	150	-	-
Banglad.	.22	.22	-	-	-	-	130	130	-	-	-	-
Belarus	.78	.81	.75	-	-	-	156 +	156 +	156 +	-	-	-
Belgium	.48	.46	.49	.38	.18	.14 -	144	143	146	143	140	142 -
Belize	-	-	-	-	-	-	-	-	-	-	-	-
Benin	.04 -	.04 -	-	-	-	-	127 -	127 -	-	-	-	-
Bolivia	.07 -	.04 -	.11	-	-	-	129	127 -	132	-	-	-
Bosnia	.36	.42	.30	-	-	-	144	145	142	-	-	-
Botswana	-	-	-	-	-	-	-	-	-	-	-	-
Brazil	.61	.75	.48	.44	.09 -	-	138	139	136	137	135 -	-
Brunei	.01 -	-	.01 -	-	-	-	127 -	-	129 -	-	-	-
Bulgaria	.91 +	.89 +	.92 +	.85 +	.53	.44	163 +	161 +	164 +	164 +	154 +	152
Cambodia	.19	.19	-	-	-	-	133	132	-	-	-	-
Canada	.76	.81	.72	.65	-	-	148	148	148	148	-	-
Chile	.18	.22	.14	-	-	-	132	133	132	-	-	-
China	.99 +	1.0 +	.99 +	.82 +	-	-	137	137	139	138	-	-
Colombia	.54	.57	.51	.34	-	-	141	141	141	138	-	-
Costa Rica	.27	.27	-	-	-	-	139	139	-	-	-	-
Cote d'Iv.	.29	.29	-	-	-	-	136	135	-	-	-	-
Croatia	.56	.58	.54	-	-	-	152	152	152	-	-	-
Cuba	.29	.27	.32	.33	.11 -	-	137	135	139	141	138	-
Cyprus	.22	.28	.16	.16	-	-	142	145	139	140	-	-
Czech R.	.66	.60	.71	.76 +	.53	.54	151	148	154	159 +	153 +	154 +
Denmark	.33	.35	.31	-	-	-	141	141	141	-	-	-
Ecuador	.12	.15	.10 -	.02 -	-	-	130	131	131	129 -	-	-
Egypt	-	-	-	-	-	-	-	-	-	-	-	-
El Salv.	.17	.17	-	-	-	-	133	133	-	-	-	-
Estonia	.37	.43	.30	-	-	-	149	152	146	-	-	-
Finland	.37	.36	.37	.39	.23	.10 -	143	142	144	147	144	141 -
France	.67	.68	.66	.73	.54	.29	142	142	143	147	147	143
Georgia	.60	.64	.55	-	-	-	153	154	151	-	-	-
Germany	.86	.86	.86 +	.89 +	.80 +	.56	146	145	147	149	151	148
Ghana	-	-	-	-	-	-	-	-	-	-	-	-
Greece	.50	.58	.43	.42	.15	-	145	147	143	145	139	-
Guatemala	.07 -	.09 -	.06 -	-	-	-	128 -	128	130 -	-	-	-
Honduras	.14	.14	-	-	-	-	132	131	-	-	-	-
Hong K.	.70	.77	.63	.61	-	-	156 +	157 +	154	155 +	-	-
Hungary	.90 +	.86	.93 +	.82 +	.88 +	.91 +	161 +	158 +	162 +	161 +	166 +	166 +
Iceland	.21	.23	.18	.12 -	-	-	146	147	144	140	-	-
India	.78	.76	.81	.61	-	-	135	134	137	136	-	-
Indonesia	.33	.49	.17	.05 -	-	-	132	134	131 -	129 -	-	-
Iran	.89 +	.88	.90 +	.55	-	-	148	146	149	142	-	-
Ireland	.23	.23	.23	.18	-	-	137	137	139	137	-	-
Israel	.71	.68	.74	.56	.30	-	157 +	155 +	159 +	154 +	147	-
Italy	.62	.69	.55	.27	.10 -	.24	141	142	141	135	136 -	142
Japan	.88 +	.91 +	.84	.65	-	-	144	144	144	142	-	-

Jordan	-	-	-	-	-	-	-	-	-	-	-	-
Kazakh.	.64	.80	.48	-	-	-	148	152	144	-	-	-
Korea, N.	.84	.94 +	.73	.67	-	-	153	155 +	150	150 +	-	-
Korea, S.	.90 +	.95 +	.85	.49	-	-	150	150	149	141	-	-
Kuwait	.04 -	.03 -	.04 -	.08 -	-	-	128 -	127 -	130 -	133 -	-	-
Kyrgyz.	.18	.27	.10	-	-	-	134	137	132	-	-	-
Latvia	.50	.44	.57	-	-	-	154	149	158 +	-	-	-
Lebanon	-	-	-	-	-	-	-	-	-	-	-	-
Liechten.	.09	.09	-	-	-	-	141	140	-	-	-	-
Lithuania	.44	.52	.36	-	-	-	148	150	145	-	-	-
Luxemb.	.17	.18	.16	.18	.04 -	-	141	141	141	144	137 -	-
Macau	.29	.37	.21	.06 -	-	-	151	156 +	145	133 -	-	-
Macedonia	.45	.45	.45	-	-	-	152	151	153	-	-	-
Malaysia	.21	.27	.15	-	-	-	132	133	132	-	-	-
Malta	-	-	-	-	-	-	-	-	-	-	-	-
Mauritania	.07 -	.07 -	-	-	-	-	129	129	-	-	-	-
Mexico	.46	.59	.33	.22	-	-	136	138	135	133 -	-	-
Moldova	.52	.66	.39	-	-	-	151	156 +	145	-	-	-
Mongolia	.53	.62	.43	.35	.12	.18	155 +	159 +	151	148	140	145
Monten.	.12	.12	-	-	-	-	135	134	-	-	-	-
Morocco	.35	.31	.38	.38	-	-	136	134	139	140	-	-
Mozamb.	.03 -	.03 -	-	-	-	-	127 -	126 -	-	-	-	-
Netherl.	.44	.43	.45	.59	.33	.11 -	141	140	143	149	145	140 -
New Zea.	.43	.45	.40	.38	-	-	147	147	147	147	-	-
Nicaragua	-	-	-	.05 -	-	-	-	-	-	130 -	-	-
Nigeria	.11	.11	-	-	-	-	128 -	128 -	-	-	-	-
Norway	.40	.39	.41	.32	-	-	145	143	146	144	-	-
Oman	-	-	-	-	-	-	-	-	-	-	-	-
Pakistan	.15	.15	-	-	-	-	129	128 -	-	-	-	-
Palestine	-	-	-	-	-	-	-	-	-	-	-	-
Panama	.15	.15	-	.02 -	-	-	134	133	-	129 -	-	-
Paraguay	.09	.11	.08 -	-	-	-	130	130	131 -	-	-	-
Peru	.42	.58	.26	.25	-	-	139	143	135	136	-	-
Philipp.	.16	.15	.16	.14	-	-	129	129	131	131 -	-	-
Poland	.76	.79	.73	.60	.53	.50	147	147	147	145	148	149
Portugal	.23	.29	.17	.12 -	-	-	135	136	134	133 -	-	-
Puerto R.	.09	.13	.05 -	-	-	-	130	132	130 -	-	-	-
Qatar	-	-	-	-	-	-	-	-	-	-	-	-
Romania	.91 +	.89 +	.93 +	.85 +	.67	.72 +	155 +	153	156 +	156 +	154 +	156 +
Russia/SU	.97 +	.98 +	.97 +	.93 +	.96 +	.88 +	145	144	146	147	152	152
Saudi A.	.08	.08 -	-	-	-	-	128 -	128 -	-	-	-	-
Singapore	.65	.71	.60	.63	-	-	160 +	161 +	157 +	162 +	-	-
Slovakia	.67	.62	.72	-	-	-	156	153	159	-	-	-
Slovenia	.38	.40	.35	-	-	-	148 +	148	147 +	-	-	-
South Af.	.48	.48	.48	-	-	-	139	138	140	-	-	-
Spain	.36	.42	.29	.29	-	-	136	137	135	137	-	-
Sri Lanka	.17	.24	.10	-	-	-	132	133	131	-	-	-
Sweden	.48	.42	.54	.46	.38	.38	145	142	149	147	148	150
Switzerl.	.38	.45	.32	-	-	-	142	144	141	-	-	-
Syria	.10	.10	-	-	-	-	129	129	-	-	-	-
Taiwan	.88	.90 +	.85 +	-	-	-	154	153	154	-	-	-
Tajikistan	.32	.32	-	-	-	-	140	139	-	-	-	-
Thailand	.65	.82	.48	.30	-	-	142	145	139	136	-	-
Trinidad	.21	.21	.21	-	-	-	139	139	140	-	-	-
Tunisia	.23	.18	.28	.27	-	-	135	132	138	139	-	-
Turkey	.76	.85	.68	.44	.12	-	145	145	144	139	137 -	-
Turkm.	.21	.37	.04 -	-	-	-	136	142	130 -	-	-	-
Ukraine	.84	.86	.82	-	-	-	148	147	148	-	-	-

United A. E.	.03 -	.03 -	-	-	-	-	128 -	127 -	-	-	-	-
United K.	.80	.77	.83	.77 +	.79 +	.72	146	144	147	148	153	152
USA	.96 +	.97 +	.95 +	.95 +	.91 +	-	142	141	143	145	149	-
Uruguay	.14	.16	.13	.12 -	-	-	133	133	134	134	-	-
Uzbek.	.45	.56	.34	-	-	-	140	142	138	-	-	-
Venezuela	.10	.16	.03 -	.10 -	-	-	129	130	128 -	131 -	-	-
Vietnam	.91 +	.91 +	.91 +	.81 +	.46	-	147	146	148	148	144	-
Yemen	-	-	-	-	-	-	-	-	-	-	-	-
Serbia	.75	.72	.78	.60	.53	.44	155 +	152	156 +	152 +	153	151
Zimbabwe	.05 -	.05 -	-	-	-	-	128 -	127 -	-	-	-	-
M	0.42	0.46	0.45	0.43	0.42	0.43	140.9	141.2	142.9	142.8	146.3	148.6
SD	0.28	0.29	0.29	0.27	0.29	0.26	9.3	9.2	8.9	8.7	7.9	6.8
N	109	107	90	60	26	17	109	107	90	60	26	17

Table 1b. Overview of country values (student assessment and other measures)

	Cognitive ability			Attributes of societies			
Country	**M**	**95%**	**5%**	**STEM**	**GDP '80**	**Econ. Freed. ('70+)**	**GDP 2007**
	IQ-scale (M=100, SD=15)			M=50 SD=10	ppp $	M=50 SD=10	ppp $
Albania	81	103	56	41.0-	1484	34.1-	4975
Algeria	82	99 -	64	46.8	2960	37.6	7267
Argentina	82	106	56	46.8	6203	41.8	16500
Armenia	94	118	70	45.3	-	-	9606
Australia	101	123 +	78	63.1	9640	60.7	39694
Austria	100	120	77	63.1	10438	56.4	38302
Azerbaijan	83	99	69	44.5	-	-	1098-
Bahrain	85	107	63	46.4	11595+	63.3	-
Banglad.	-	-	-	40.6-	696-	29.0-	2470
Belarus	-	-	-	53.5	-	-	24072
Belgium	99	120	76	61.9	9993	66.7+	35953
Belize	65 -	91 -	43 -	45.1	2956	47.0	9854
Benin	-	-	-	43.5	545-	46.1	1491-
Bolivia	-	-	-	43.0	1825	40.1	4103
Bosnia	91	111	70	42.8-	-	-	6439
Botswana	75 -	97 -	52 -	45.1	1622	47.0	10169
Brazil	82	105	60	44.4	4275	49.6	10056
Brunei	-	-	-	46.9	29244+	-	52103+
Bulgaria	94	118	68	46.5	2457	42.7	10605
Cambodia	-	-	-	46.9	458-	-	3015
Canada	102 +	122 +	81 +	60.9	10831	67.6+	39088
Chile	85	107	62	46.4	3715	35.0-	21548
China	106 +	125 +	86 +	46.3	488-	38.4	8653
Colombia	82	102	60	46.3	2665	49.6	8379
Costa Rica	-	-	-	45.9	4280	53.0	12353
Cote d'Iv.	-	-	-	46.9	1324	46.1	2377-
Croatia	96	115	76	49.1	-	39.3	14861
Cuba	-	-	-	46.9	3426	-	11762
Cyprus	92	114	69	47.0	4438	50.4	26780
Czech R.	100	121	78	47.8	-	53.8	23125
Denmark	99	119	77	65.3+	9130	60.7	36198
Ecuador	-	-	-	43.5	3238	35.8-	6510
Egypt	82	108	55	43.1	1400	37.6	6142
El Salv.	79	97 -	60	43.6	2508	41.0	5926
Estonia	102 +	121	84 +	51.7	-	50.4	20977

Finland	103 +	122	84 +	57.4	8988	61.6	33911
France	98	119	76	60.5	9744	57.3	31446
Georgia	88	108	67	45.7	-	-	9184
Germany	100	121	76	61.3	9727	66.7+	33181
Ghana	63 -	90 -	35 -	44.5	896-	31.6-	1814-
Greece	95	116	72	46.5	7942	57.3	29482
Guatemala	-	-	-	43.5	2864	53.8	6445
Honduras	-	-	-	42.1-	1819	51.3	3796
Hong K.	104 +	123 +	83 +	49.8	7676	74.4+	45446+
Hungary	100	120	78	54.1	5221	40.1	18041
Iceland	97	117	75	47.9	11416	56.4	40907
India	-	-	-	43.2	704-	47.0	4099
Indonesia	82	101	63	46.1	1141	45.3	5468
Iran	84	105	61	44.2	3081	60.7	10739
Ireland	100	120	78	61.7	6504	59.8	43351
Israel	93	118	65	56.8	6891	44.4	25301
Italy	97	118	74	51.9	8862	53.8	30505
Japan	105 +	125 +	82 +	69.4+	9264	57.3	32063
Jordan	86	109	61	45.7	3113	48.7	5562
Kazakh.	83	105	61	46.5	-	-	17275
Korea, N.	-	-	-	46.9	-	-	-
Korea, S.	107 +	126 +	86 +	53.9	2687	47.8	24949
Kuwait	77	99 -	54	42.1-	23880+	51.3	47753+
Kyrgyz.	71 -	94 -	47 -	46.8	-	-	4024
Latvia	98	118	77	47.6	-	43.6	16333
Lebanon	84	107	62	45.8	4456	-	8228
Liechten.	102	122	79	46.9	-	-	-
Lithuania	97	117	76	47.2	-	44.4	15330
Luxemb.	99	120	76	99.9+	14023+	64.1+	88335+
Macau	101	118	83 +	45.0	6082	-	50485+
Macedonia	85	108	61	45.4	-	-	7641
Malaysia	96	117	75	53.9	2988	57.3	19012
Malta	93	117	64	47.7	3899	47.8	23006
Mauritania	-	-	-	46.9	1041	42.7	2417-
Mexico	86	106	66	47.8	4709	56.4	12026
Moldova	93	114	70	46.3	-	-	3785
Mongolia	88	107	68	43.3	873-	-	3711
Monten.	84	105	63	-	-	-	7434
Morocco	72 -	96 -	49 -	48.1	1902	52.1	5720
Mozamb.	-	-	-	43.6	837-	-	2306-
Netherl.	102 +	121	82 +	63.1+	10452	65.0+	36394
New Zea.	100	124 +	76	59.1	7330	56.4	27439
Nicaragua	-	-	-	50.2	1709	35.8-	2305-
Nigeria	-	-	-	42.8-	866-	33.3-	2519
Norway	96	117	74	66.5+	11866+	54.7	53967+
Oman	82	105	57	46.9	7969	58.1	25383
Pakistan	-	-	-	41.2-	989	41.0	3675
Palestine	81	107	54	-	-	-	-
Panama	78	102	54	45.9	2440	58.1	9480
Paraguay	-	-	-	42.1-	2459	50.4	4912
Peru	76	99	52 -	43.9	2895	44.4	7245
Philipp.	75 -	102	48 -	51.5	1740	48.7	4822
Poland	98	119	75	46.8	3915	36.7-	15447
Portugal	93	113	72	47.4	5067	55.6	21526
Puerto R.	-	-	-	46.9	5202	-	27715
Qatar	74 -	99	51 -	46.9	37232+	-	104707+
Romania	90	112	67	45.9	3856	44.4	10506
Russia/SU	98	119	76	55.7	-	39.3	14669

Saudi A.	76 -	96 -	54	48.5	12477+	-	22391
Singapore	105 +	128 +	80	70.4+	6660	67.6+	48489+
Slovakia	98	119	76	55.2	-	49.6	18172
Slovenia	99	119	77	51.4	-	44.4	27867
South Af.	65 -	101	38 -	49.3	4389	55.6	11306
Spain	96	116	75	48.9	7034	57.3	33615
Sri Lanka	-	-	-	43.5	1088	45.3	6270
Sweden	100	121	78	76.4+	10090	52.1	35270
Switzerl.	100	121	77	87.4+	13259+	69.3+	39161
Syria	82	106	65	41.4-	1131	42.7	2689
Taiwan	103 +	123 +	80 +	46.9	3362	63.3	27883
Tajikistan	-	-	-	46.0	-	-	3018
Thailand	90	110	71	48.9	1628	53.0	10302
Trinidad	85	111	57	46.6	8257	41.0	29394
Tunisia	82	101	61	43.6	2762	42.7	10641
Turkey	88	111	67	42.8	2037	34.1-	8101
Turkm.	-	-	-	46.9	-	-	12118
Ukraine	94	114	71	53.8	-	35.8-	11173
United A. E.	93	117	67	46.9	40009+	53.8	57259+
United K.	100	123 +	76	67.6+	8345	54.7	34319
USA	99	121	75	66.7+	12158+	64.1+	45597+
Uruguay	88	112	62	44.2	4554	49.6	13608
Uzbek.	-	-	-	50.8	-	-	2208-
Venezuela	-	-	-	43.1	5323	66.7+	13721
Vietnam	-	-	-	44.1	520-	-	3731
Yemen	65 -	85 -	45 -	41.0-	-	-	1172-
Serbia	91	112	68	45.8	-	-	-
Zimbabwe	-	-	-	42.9	1447	40.1	2448-
M	90.3	111.9	67.7	50.00	6059	50.00	19031
SD	10.6	9.5	11.3	10.00	6815	10.00	17806
N	93	93	93	119	94	92	116

Note: As country names the normally used names; all standardized and unstandardized scales are somewhat arbitrary (e.g., gross domestic product, or GDP, and inflation, IQ and reference groups); *IMO scores* for the International Math Olympiad were based on relative rank in each decade (scale runs from 0 to 1), relative to number of participating countries, *M 91-10*: relative rank in IMO 1991-2010; relative rank and population size: relative to number of participating countries and to population size of country, transformed to IQ-scale; *Cognitive ability*: cognitive ability mean in student assessment studies normed according to UK ("Greenwich-norm"), transformed into IQ-scale; *95%*: cognitive ability mean at 95th percentile, IQ-scale; *5%*: cognitive ability mean at 5th percentile, IQ-scale; *STEM*: science, technology, engineering, and math achievement indicators, transformed to a T-scale (M = 50, SD = 10), outlier Luxembourg (due to patent rate) set on 99.9; *GDP 1980*: Gross Domestic Product 1980 using purchasing-power parity (ppp); *Econ. Freed. ('70+)*: Economic freedom 1970 or earliest measurement point, transformed to T-scale; *GDP 2007*: Gross Domestic Product 2007 ppp; the top 10 countries in each category are marked with a "+," the bottom 10 countries were marked with a "-." For variables with less then 50 countries, only the top and last 5 were marked, with less than 20 only the top and last 3.

5 Method

Table 1 shows data adjusted for *relative rank* and *relative rank and population size* for recently measured data (1991-2010) and for the decades 2001-2010, 1991-2000, 1981-1990, 1971-1980, and 1959-1970. Because the population-based estimate is not on a "natural" scale, it was transformed to an IQ scale oriented on the values of the cognitive-ability mean at the 95th percentile, with

30 added IQ points (a modest estimate, e.g., for Britain IQ 146).[5] For population size, data (around the year 2000) from Kurian (2001) were used.

These data are accompanied by IQ-scale-transformed results from student assessment studies (TIMSS, PISA, PIRLS from 1995-2009) for the *mean*, the *95th percentile*, and the *5th percentile*. They were compiled using the same procedure as described in Rindermann et al. (2009), with three differences: PISA 2009 scores were included; the outlier Kazakhstan from TIMSS 2007, 4th grade, was deleted (and data from PISA 2009 were substituted); and data for Mongolia (TIMSS 2007, 4th and 8th grade) were added. The level of the 95th percentile indicates the cognitive-ability level of the intellectual class (the lower threshold of the top 5%).

STEM was measured by patent rates, Nobel Prizes in science, numbers of scientists, and fraction of high-technology exports in a given country; the first three were adjusted for population size (cf. Rindermann et al., 2009).

Productivity and *wealth* indicators were gross domestic product (GDP) for 1980 and 2007, as listed in the Penn World Table Version 6.3 (per capita purchasing-power parity, in analyses using logged data).

Economic freedom ratings for 1970 (or first measurement point in the 1970s) were obtained from the Fraser Institute (see Rindermann, 2008a).

Psychometric IQ data and estimates from Lynn and Meisenberg (2010) and Lynn (2010) were combined by the author of the present article and, if countries were missing, completed by older data from Lynn and Vanhanen (2006). IQs of countries with no psychometric IQ data were estimated by Lynn using the means of neighboring countries. Rindermann corrected the estimated values by –4 IQ points if countries also did not participate in student assessment studies (no data as an indicator of detrimental conditions for cognitive development in a country).

International data are not error free, nor are numbers like GDP (e.g., in 2007, Azerbaijan seemed to be the poorest country in the sample from the Penn World Tables).

6 Empirical results

Not corrected for population size, China produced the top math students (see Table 1 and Fig. 1). Next came (2) Russia, (3) USA, (4) Vietnam, (5) Romania, (6) Bulgaria, (7) South Korea, (8) Hungary, (9) Iran, and (10) Japan. India, Turkey, and Israel also produced a large amount of top performers in math. The fact that smaller countries (Romania, Bulgaria, Hungary, and Israel) ranked so highly is remarkable.

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[5] It may be hard to believe, but there are no IQ measurements of IMO participants.

Figure 1. World map showing relative ranks on the International Mathematical Olympiad, not corrected for population size (based on mean data from 1991 to 2010, N = 109 nations). Darker shading indicates higher rankings; no data were available for hatched areas.

Figure 2. World map of relative ranks on the International Mathematical Olympiad, adjusted to population size (based on mean data from 1991 to 2010, N = 109 nations). Darker shading indicates higher rankings; no data were available for hatched areas.

When corrected for population size, the results changed: Smaller countries rose to the top (see Table 1 and Fig. 2): (1) Bulgaria, (2) Hungary, (3) Singapore, (4) Israel, (5) Slovakia, (6) Belarus, (7) Hong Kong, (8) Mongolia, (9) Romania, and (10) Yugoslavia (Serbia). Other East European and Asian countries (e.g., Taiwan, Latvia, Georgia, Koreas, Croatia, Armenia, Macao, Estonia) also achieved good results. On the other side among participating nations, are countries from Arabian-Muslim, Latin American, and sub-Saharan regions.

Table 2: Correlations

	IQ (psychometric)		**Cognitive ability** (SAS)			**Attributes of societies**			
	not corrected	corrected	**Mean**	**95%**	**5%**	**STEM**	**GDP 1980**	**Economic Freedom**	**GDP 2007**
IMO (r)	.58 (.46)	.58 (.46)	.44 (.44)	.48 (.47)	.39 (.39)	.22 (.25)	.37 (.35)	.13 (.28)	.27 (.46)
IMO (rrp)	.68 (.57)	.68 (.57)	.53 (.53)	.56 (.55)	.47 (.47)	.27 (.43)	.61 (.61)	.22 (.45)	.38 (.70)
N	108 (81)	108 (81)	82 (81)	82 (81)	82 (81)	108 (69)	71 (69)	84 (69)	105 (69)

Note: IMO (r): relative rank in the IMO from 1991 to 2010, relative to the number of participating countries; IMO (rrp): relative rank, relative to the number of participating countries and to the population size of each country in the IMO from 1991 to 2010; Cognitive ability (SAS): cognitive ability measurements with student assessment studies, cognitive ability mean, at 95th percentile, at 5th percentile; STEM: the arithmetic mean of science, technology, engineering, and math indicators; GDP 1980: Gross Domestic Product 1980, purchasing power parity, log transformed; Economic freedom: Economic freedom 1970 or later; GDP 2007: Gross Domestic Product 2007, ppp, log transformed; cognitive measures in a second version analyzed in one common country sample (listwise deletion, in parentheses); STEM and economic measures in a second version were analyzed in one common country sample (listwise deletion, in parentheses).

The Math Olympiad ability indicators correlated fairly highly with general indicators of cognitive ability (see Table 2). The correlations with IQ measures were also (but not only) higher because of the larger country sample, which included countries with low educational levels that did not participate in PISA, TIMSS, and PIRLS. Within the student assessment results, the 95th percentile level (r = .56) correlated higher with Math Olympiad ability than did the mean level (r = .53) or the 5th percentile level (r = .47). This result supports the validity of both variables as indicators of the intellectual class' cognitive ability level. [6]

Countries with better achievement in the Math Olympiad also showed better results in STEM (r = .27 [.43]), they are economically freer (r = .22 [.45]) and

[6] The higher correlation with the 95th percentile is not caused by the anchoring procedure of the IMO results on the 95th level, because this procedure leads only to the addition of a constant and a linear transformation of the standard deviation.

more wealthy (r = .38 [.70]), especially (in a common country analysis) in more recently measured wealth.

Generally, the Math Olympiad ability indicator correlated more highly with other ability variables and with STEM and economic variables when it was corrected for population size than when it was not. This supports the validity of the correction procedure.

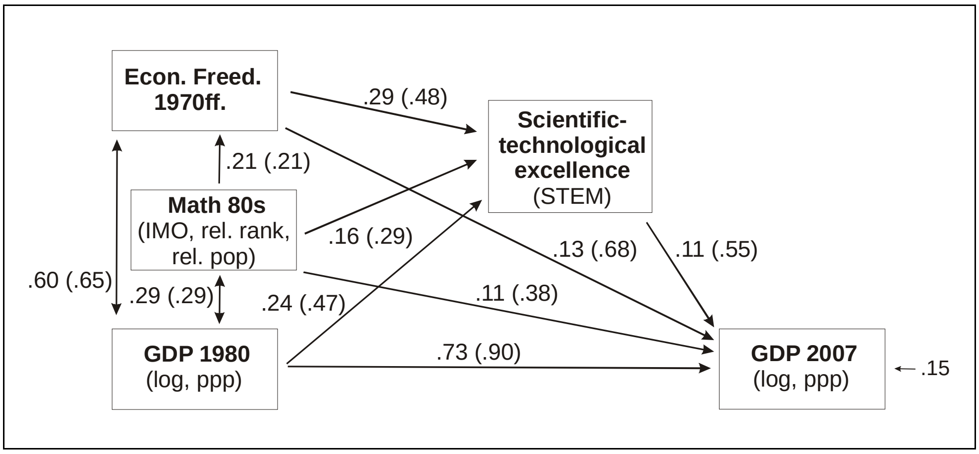

Figure 3: Path model showing that produced national wealth in 2007 was dependent on former wealth (gross domestic product, or GDP, from 1980), economic freedom, IMO results in the 1980s (as an indicator of the cognitive level of an intellectual class), and achievements in science, technology, engineering, and math (STEM). N = 120 nations, FIML, saturated model; ppp = purchasing-power parity.

In a longitudinal path model (see Fig. 3), the 1980s IMO results are used as an indicator of the influence of cognitive level of the intellectual class of a country (relative rank and relative to population size) on wealth (GDP 2007). The most important factor for wealth 2007 is former wealth. This is trivial because the future can usually be predicted best by the past, and the same is true for wealth differences. But the correlation between wealth in a nearly 30 years distance is not r = 1, which means there is change in the relative wealth levels of nations. What possible determinants could explain change in wealth? The other three predictors are of similar size: Economic freedom ($\beta_{EF \rightarrow GDP07}$=.13), STEM ($\beta_{STEM \rightarrow GDP07}$=.11), and IMO-ability level ($\beta_{Math \rightarrow GDP07}$=.11). It was assumed that IMO (as an indicator of the ability level of the intellectual class) also has indirect effects on current wealth through economic freedom and STEM, resulting in a total effect of $\beta_{Math \rightarrow GDP07}$=.13 (economic freedom total: $\beta_{EFG \rightarrow GDP07}$ =.16). STEM depends not only on cognitive competence, but also on wealth and economic freedom, the latter possibly a general indicator of freedom, competition, and organization of society by merit. Compared with a cross-sectional study using SASs (Rindermann & Thompson, 2011), the effect of economic freedom is slightly larger than the intellectual-class effect using IMO results.

7 Usefulness of IMO data

The use of IMO data for international competence comparisons and econometric analyses reveals important results: First, mathematics achievement is substantially correlated with more general (broader content), more representative (broader samples of age cohorts), and less selected (also students and adults from average ability levels) results of student assessment studies and psychometric cognitive-ability studies. Second, IMO data help to predict wealth, changes in wealth between nations, and the relative increase of wealth. Third, IMO results taken as indicators of the cognitive-ability level of an intellectual class stimulate scientific-technological progress. This progress is at least partly a competence-based technological progress.

IMO results have to be corrected for number of participating countries and, in a more difficult calculation, for population size. The distribution of results hints that the findings could depend on political valuation of IMO competitions, as investment in the search, selection, and training process of gifted students. Maybe there is also some influence in the scoring process; for example, North Korea was twice disqualified for cheating. But similar problems could also happen in the student assessment studies, for example, by exclusion of the weaker students (“holidays” at testing days), help during the test, or simple low school-enrollment rate of weaker youth.

Nevertheless, the correction procedure produced valid data, as shown by the correlations with other indicators of cognitive ability, especially of the intellectual classes. To broaden the construct and database, future research should look at results of other Olympiads in science (physics, chemistry, biology, astronomy), informatics, geography, and, if comparable, linguistics and philosophy (however, only the Olympiads in physics and chemistry could provide data for longitudinal studies since the end of the 1960s). Longitudinal research should also look for possible determinants of IMO achievement and changes in IMO achievement between countries across time.

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