Mathematics and Science Olympiad Studies: The Outcomes of Olympiads and Contributing Factors to Talent Development of Olympians

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Abstract

The purpose of this article is to review *Mathematics and Science Olympiad Studies.* The studies undertook the task of evaluating the effectiveness of chemistry, math, and physics Olympiad programs by tracking down their participants from the inception of these programs. The main research questions were: Do these competitions generate creative professionals in Science, Technology, Engineering and Math (STEM) and do their graduates make important contributions? What are the crucial factors for their success in STEM careers? To answer these questions, surveys and instruments were synthesized and administered to Olympians and to their parents. For 11 years, 1,093 Olympians in six countries were tracked down to find out their careers and their accomplishments and the factors contributing to these successes. These academic competitions were found to make a strong contribution to STEM talent development and produce creative STEM professionals. Crucial contributing factors commonly found across countries were:

1. Early recognition of STEM talent and conducive home environment;
2. Specialized challenging programs for developing strong STEM foundations and opportunities to participate in STEM activities and competitions during the schooling period; and,
3. Strong motivation and efforts on the part of the Olympians for success throughout the developmental stages.

Keywords: Mathematics and science; STEM; olympiad; talent development; cross-cultural.

Introduction

Every educator's ultimate goal is to develop children's talents. This goal becomes especially challenging for teachers and parents when children exhibit extraordinary talents. This article is about an alternate approach (academic competitions) to nurture STEM talents.

Plato recommended providing such programs for the gifted, but it was China (Han dynasty 141-87 BC) that instituted examinations to identify the gifted for civil service positions. Other dynasties (Tiang, 920-1127; Sun 629-755) expanded and codified the extent of these examinations.

With the development of intelligence-testing instruments (1890-1918), Lewis Terman [48] and Leta Hollingworth [24] realized that gifted students with exceptional talent could be identified. Using the newly developed Stanford-Binet test, Terman [51] launched his Genetic Studies of Genius in California. His research team tracked high IQ students over decades and concluded that these IQ tests do not predict what direction the achievement will take. Both interest patterns and special aptitudes play important roles in the making of a gifted scientist, mathematician, mechanic, artist, poet, or musical composer [53].

In New York city, Hollingworth [24] used this test to isolate over 100 exceptionally-gifted students. She also started a special school for such students. The one alternative available in the 1920s to 1950s for gifted students was acceleration (grade skipping). Placing such students in advanced grades provided challenges. But American schools did not initiate programs for the gifted and talented until after World War II. After the war, schools instituted a number of alternatives that included separate classes within schools, enrichment programs, compacting, self-pacing, Advanced Placement (AP) courses, pull-out programs, cluster grouping, summer programs, and full-time schools for the gifted.

These programs, unfortunately, did not produce enough Science, Technology, Engineering, and Math (STEM) scientists to meet national demands. Eventually, the need for STEM personnel instigated International STEM Olympiads. Professional organizations undertook programs to foster the development of talent in their own technical domain. Three professional organizations (American Chemical Society, The Mathematical Association of America, and the American Institute of Physics) initiated programs to identify the most talented students in their domains (Chemistry, Math, and Physics Olympiad competitions). In these programs authentic performance, not IQ tests, were essential in selecting students. These programs provided extremely talented individuals in STEM with in-depth domain experiences and social supports.

The nature of these programs is aligned with theoretical and empirical studies which are based on the Talent Development Paradigm [13, 21, 39, 43, 44]. The Talent Development Paradigm acknowledges that STEM talent takes a unique developmental trajectory. STEM talent is demonstrated early with strong interest and abilities in mathematical and spatial reasoning (30). This paradigm emphasizes motivation, timely opportunity for training, coaching, in-depth domain experiences, and technical and social support as crucial factors for STEM talent development [12, 15, 17, 20, 36, 37].

The fundamental question that needs to be answered for these school-based or professional organization-based talent development programs is, "Do these programs achieve their objectives; i.e., do their graduates select STEM careers?" Researchers need to follow yearly cohorts into adulthood to quantify any contributions. Terman's (51) Genetic Studies of Genius followed this pattern, but this was not the case for other alternative innovations. Only one alternative -- the Study of Mathematically Precocious Youth (SMPY), a summer program, did any systematic follow-ups [31, 32, 42, 59].

Another intriguing question for educators and researchers is, "What are the influential factors for STEM talent development?" Several studies investigated factors that are influential for talent development. Various psychosocial factors were found to be related to productive creativity of talented individuals. They include general and specific abilities [30], interest [33, 41, 46], motivation [14, 39], and opportunities for appropriate learning [41, 45, 47, 59, 65].

Not many studies examined the influential factors along the developmental stages of STEM talent. Influential psychosocial variables change as talented individuals go through developmental stages across their life-span [44]. In order for abilities to be transformed into competencies, parents' recognition of talents and early provision of rich and conducive home environment will help talented children fall in love with activities in specific domains such as music, mathematics, or figure skating. However, there is very little literature about the influence of family and teachers in the early stage of STEM talent development. During the middle stage when most of the Olympians participate in competitions, their competencies are transformed into expertise. During this process teachers and mentors are crucial. For example, in specialized science high schools, students are engaged in research involving real problems and nurturing the modus operandi of a profession [9]. STEM talent development requires long-term involvement in STEM domains. It is necessary to proactively develop an agenda in educational programming that addresses unique advancing needs of talented students [16, 31, 59].

Most innovations in education by the schools do not evaluate their product to any extent. Follow-ups are rarely built into the evaluation process. To fill this void, the academic *Olympiad Studies* undertook the task of evaluating the effectiveness of the Chemistry, Math, and Physics Olympiad programs by tracking down their participants from the inception of these programs. Do these competitions generate STEM scientists? Do their graduates make important contributions?

To answer these questions, surveys and instruments were synthesized and administered to Olympians and their parents. We spent 11 years tracking down 1,093 Olympians in six countries to find out the careers they chose and their accomplishments. As of 2006 the oldest Olympian was 41 and the youngest was 16.

Methods and Data Sources

The international Olympiad studies began in 1995 with research teams in Taiwan (Wu-Tien Wu), Mainland China (Zha Zixiu), and the United States (Campbell). In 1997 additional teams joined the project from Germany (Kurt Heller), Finland (Kirsi Tirri), and Korea (Seokhee Cho) (see Table 1 - found at the end of the research or p. 21). Furthermore, researchers in Japan [Hirano, 23] and Russia [Kukushkin, 28] contributed articles about the Olympiad programs in their countries.

Table 1: International Academic Olympiad Principal Investigators and Samples.

Samples	**N**
American Olympians (1998-2007) *PI: James Reed Campbell, St. John's University*	335
German Olympians (1998-2007) *PI: Kurt Heller, University Munich*	235
Finland Olympians (1998-2007) *PI: Kirsi Tirri, University of Helsinki*	165
P.R.C./R.O.C. (1998-2000) *PI: P.R.C. Zha Zixiu Chinese Academy of Science* *PI : R.O.C. Wu-Tien Wu, Taiwan Normal University*	71
Korean Olympians (2005-2007) *PI: Seokhee Cho, St. John's University*	277
Totals	1,093

Our studies are retrospective in nature because we asked the Olympians and their parents to supply information about the Olympians when they were growing up. Our fundamental research question was, "What factors contributed or hindered the development of their talents?" Our inspiration for doing these studies originated from a deep appreciation of the Terman longitudinal studies that began in the 1920s-1930s and continues to this day [48, 49, 50, 51, 52].

Terman [51, 52] wanted to find out if developing talent early led to early burnout (early ripen, early rot). He found that many of his gifted subjects did not burn out and led productive lives. Some, however, did not. His subjects were mainly high IQ individuals.

The Olympiad programs require extensive domain knowledge. High school students take a series of technical exams to emerge as the top 20 students in their country. We have representations from the US, Asia, Europe and from one of the Nordic countries.

The Olympiad studies are unique in devoting so much effort to parents. We sent parallel surveys to parents and included an instrument that captures the parental-involvement dimensions used during the development years. These surveys used mixed methods producing both quantitative and qualitative data.

The principal investigators and their talented colleagues collaborated extensively with data collection, analyses, statistical methods, and publishing throughout the many years of contact. This collaboration deepened our own research expertise.

In getting the same information from the Olympians and their parents, we were able to validate the information that was collected. In order to secure qualitative data, we included open-ended questions for the Olympians and their parents.

For researchers not familiar with the Olympiad studies, the excerpts below list key findings from some of the articles and research papers presented at international meetings. For each listing the author's contribution is included in the reference section.

Major findings of Mathematics and Science Olympiad Studies

Evaluation of Olympiad Programs

The first round of studies with the Math Olympians asked the question, "Would you have achieved as much without the Olympiad program?" In Mainland China, 89% of their Olympians and 90% of their parents expressed the view that the Olympians would not have accomplished as much [64, p. 538]. The Taiwan Olympians (66%) expressed the same view [60, p. 530], and 76% of the American Math Olympians and 70 % of their parents voiced the same belief [3, p. 504]. To understand these conclusions consider the national recognition provided by Olympiad programs which helped them to get into elite universities.. The American Olympians were recruited into ongoing research programs under way at these universities. In subsequent rounds of data collection, the same findings occurred. Keep in mind that our principal investigators had no connection to these programs and were seen by the Olympians and their parents as objective evaluators.

Gender Gaps

After the second round of data collection, our international researchers reported large gender gaps in the three STEM domains. The German Olympians had the largest gaps between males and females (math 35:1; physics 95:0; chemistry 10:1). Math had the least female Olympians. We then conducted five qualitative follow-up studies [54, 29, 18, 6, 63, 11]. One introductory article [2] and a summary article [35] accompanied these articles. These studies interviewed both male and female Olympians and asked their views about these gender gaps. The key findings attributed the causes to cultural forces in each of the countries.

In Germany the male Olympians placed the blame on the bias by teachers against girls. The male Olympians believed there was really no talent differences between the sexes. In Korea, female Olympians attributed their success to the support from their family members. Finnish-male Olympians identified early reading and math experience as influential more than females did. The male Olympians had been given more early encouragement in mathematics and the sciences [54] and had taken part in more competitions than the females [54, 58]. Both males and female Olympians identified international co-operation as the single most influential factor for academic success and then a supportive partner as critical to their success [58].

Peoples Republic of China Olympians

Mainland China started their Olympiad programs in 1985. Nevertheless, by 1996 ten million students participated annually. Special programs for the gifted are credited with nurturing the Math Olympians [64]. These programs are initiated because the Chinese believe that these gifted students will emerge as leaders in the next generation. This research team isolated four factors that they believed are responsible for developing such extraordinary math talents:

- Positive home atmosphere and parents' influence on early education;
- Solid foundation in math provided by the schools;
- Guidance and encouragement of excellent teachers; and,
- Psychological stability and effort by the Olympians.

Republic of China (Taiwan) Olympians

In Taiwan, due to the Chinese cultural tradition, gifted education is a top priority with the expectation that children in such programs will become the leaders in the next generation [60, 61, 62]. Taiwan began its Olympiad program in 1991. Most of the math Olympians identified were first-born in their families, came from higher SES (Socio-Economic Status) families, and reported that their teachers were critical in the development of their talents. Most of these Olympians can concentrate easily, prefer thinking to memorizing, are curious about many things, were involved in extracurricular activities, were largely independent, and were good time managers. Also critical in their development were conducive home atmospheres where mothers provided more intellectual resources and more monitoring than fathers.

Japanese Olympians

As of 1996, in Japan there were no gifted programs for the academic Math Olympians [23]. Hirano [23] believes that the system of standardized and conformist education is not able to develop fully such children's full potential. Math is taught at a high level in Japanese high schools, which assures a steady stream of talented students to participate in the Olympiad contests. Hirano [23] points out that 40% of the less-talented students cannot understand the math that is being taught.

Russian Olympiad Competitions

The U.S.S.R. (Union of Soviet Socialist Republic) initiated academic Olympiad programs in 1934 [28]. This innovation spread first to the satellite countries surrounding Russia, then to western countries, and eventually around the world. Kukushkin [28] provides information about how Russian mathematicians and STEM scientists developed the program that became so successful and replicated worldwide.

German Olympians

The German Olympians come from intact families (2-3 children) where parents are highly educated with high-status jobs. Over 50% of the mothers stayed at home during the child-rearing years [22]. Parents recognized the child's talent by 7-8 years of age. The most important factor during the developmental years was a conducive home atmosphere where high levels of literacy existed. Additionally, many of the Olympians attributed their success to their own motivation, effort, initiative, and curiosity. Furthermore, German Olympians put more stock in ability than effort. Male Olympians greatly outnumbered females in Germany (highest gender gap). The German Olympians also reported hindrances in their schools that included classes taught at low levels of instruction, and schools not providing sufficient challenges. The German Olympians mostly stayed with their academic domain throughout their careers.

Finland Olympians

Finland's Olympians were mostly the first-born child in large higher SES families [55]. The mothers in Finland had the highest level of education than any of the other countries participating in these studies. Parents and Olympians reflecting on the three most important factors that contributed to the development of their Olympians' talent were as follows: 1. conducive home atmosphere; 2. homes that included abundant reading resources; and 3. excellent teachers. Finland is known for its excellent teachers. Finland provides no special programs for the gifted because it is believed that every child has gifts. Instead, equity is emphasized. The Olympians reported few school hindrances with the exception of courses being taught at too low a level. However, some of the Olympians reported bullying, harassment, ignorance, envy, and jealousy. Asked to identify the most important person in the development of their talents, the Finnish Olympians in all SES groupings rated themselves.

The Finnish Olympiad participants in particular have been highly independent learners, and they attribute their academic success to both ability and effort [56]. Their own interests and efforts have been the key factors in developing their talents and in their career orientations. According to the Olympians themselves, the Olympiad program increased their self-confidence and confirmed the career choices they had already made. Finnish Olympians have been motivated largely by their own inner drive. A favorable home atmosphere and the supportive teachers were helpful, but the Olympians viewed themselves as the most influential person in developing and actualizing their mathematical talents (57). In higher SES families they also rated their parents. Furthermore, middle and low SES families, also listed their teachers.

Korean Olympians

Korean Olympians were mostly the first-born or only child (54.5%) in families with high literacy where their mothers recognized their talents during the preschool years [10]. Most of these Olympians did not attend programs for the gifted, but 71.4% attended specialized science high schools. The most important factors that fostered the development of their talents included: parents' recognition and encouragement, conducive home atmospheres where high levels of literacy existed, acceleration (skipping grades), taking advanced courses, and teachers' support. Almost all of the Korean Olympians enjoyed reading books. These Olympians, however, reported certain negative school influences such as poor and disrespectful teachers and not enough challenges in their high school classes. Shim and her colleagues [40] found 277 Korean Olympians in 2005. Among the sixty Olympians who responded to the survey, 74.4% majored in natural sciences and engineering, 20.4% in medical science, and 5.2% in other fields.

American Olympians

The doctoral degrees earned by the American Olympians are listed in Table 2 (last page of research or p. 22). We included law degrees because some of the Olympians transitioned to careers outside their domains. Most of them got their doctorate at age 30. As the years proceed we believe that more Chemistry, and Physics Olympians will get their doctorates so that the American average is 50%. Most American Olympians graduated from the most prestigious universities (in rank order: 1. Harvard, 2. MIT, 3. Princeton, 4. U.C. Berkley, 5. Stanford, 6. U. Chicago, 7. U. Illinois, 8. Duke, 9. Cambridge (UK), 10. Cal. Tech.).

Table 2: American Olympians' Doctoral Degrees (Ph.D., MD, JD) (2007).

Domain	Age Range	Percentage
Mathematics	15-51	57
Chemistry	15-42	49
Physics	15-39	41

We have data from 70% of the Physics and Chemistry Olympians and 90% of the Math Olympians. Virtually 100% of these individuals have earned college degrees. In terms of careers, most of the Olympians end up in three STEM areas: university professors, computer, or scientific occupations.

In terms of publications, the 90 young Olympians (ages 16-22) averaged 5.09 publications; the 131 early career Olympians (ages 23-29) averaged 15.86 publications; and the 124 mature career Olympians (ages 30-41) averaged 49.14 publications. By 2007 the total publications for these Olympians was 8, 629.

The American culture places value on sports and competitions [7]. Some Chinese educators see this as a major weakness, but the Americans have turned it into an advantage. There are 265 academic competitions in the United States in every academic domain [25]. Eighteen percent of American secondary students (grades 9-12) participate in competitions [7].

Over 50% of the American Olympians were immigrants or the children of immigrants [3]; therefore, this was a way for levelling the field of opportunity to newcomers. Most competitions are not run by the government but maintained and nurtured by teachers who do so to provide challenges to these talented students. This grass roots origin is one of America's strengths. The Olympians were mostly the first-born child (66%) in small (1.4 children) professional families with high-status jobs. However, some Olympians came from very low SES families. Most of them attended public schools (84%) where 56% of these schools provided programs for the gifted.

Two negative hindrances were reported by the Olympians about their schools: 1. negative effects in the elementary schools where precocious children were taunted for their talents; 2. school hindrances (poor or disrespectful teachers, classes taught at too low a level, boredom). The factors that had positive effects on the Olympian long-term productivity included a conducive home atmosphere when they were growing up and early recognition and encouragement of their talents by their parents [4, 8].

Discussion

The key finding is that home-based/school-related factors account for the development of Olympian's talents as adults [33]. Regarding home factors, a conducive home atmosphere during their growing-up years was largely responsible for the development of their talents. Another home factor, namely, the family's SES, also contributed to their development. High SES families provided the needed intellectual resources.

With regards to school factors, negative effects during the early school years had damaging consequences on the development for some of the American Olympians. The young prodigies had serious negative confrontation with their peers. Hindrances by teachers and administrators were also experienced by many Olympians. These obstacles proved frustrating to the Olympians and their parents. In almost every country the Olympians mentioned teachers that were disrespectful to their talents. Some Olympians reported knowing more about their subject than their teachers; classes taught at too low levels; and schools not providing enough challenges.

It was surprising to find some Olympians with low motivation. Our recent studies have labelled this factor as Low Ambition. Our studies of adult Olympians found that low ambition continues into their careers and lowers their productivity [4].

Crucial factors for STEM-talent development emerged along the developmental stages as well as suggested by various theories based on the Talent Development Paradigm [12, 15, 17, 20, 36, 37, 44]. Concerning the early developmental stage, positive or conducive home atmosphere, parents' recognition of talents, and high SES of families providing rich intellectual stimuli were very critical. These findings are very similar to what many other studies [1, 30, 31, 41] found. On the middle developmental stage, establishing solid foundation in math through challenging programs and encouragement by excellent teachers were reported as critical factors for successful STEM- talent development [41, 45, 47, 59, 65].

In addition, psychological traits and efforts of the Olympians at all stages were essential for their success as found in previous studies [14, 38]. The psychological traits include motivation, initiative, curiosity, independence, time management skills, and strong concentration. However, attribution of their success or failure was different among Olympians from different countries [5]. European and Nordic Olympians attributed their success to their own motivation, effort, initiative, and curiosity, whereas, more Asian and American Olympians attributed their success to parents and teachers [34]. These differences could be from the cultural influence of individualism versus group collectivism.

In early school years some Olympians experienced negative school atmospheres and teachers. European Olympians responded low-level instruction as a hindering factor, whereas in China, Japan, Korea, and the United States, Olympians responded that they were provided with challenging programs regardless of the existence of gifted education programs. More than half of the American schools provided programs for the gifted. Some Korean and American Olympians reported disrespectful teachers toward their talents as hindering factors.

Would it be unrealistic to expect school teachers to provide appropriately-challenging programs to these STEM talented students in the school setting? If formal recognition of the STEM talent is made, would it be possible for them to be provided with appropriate programs?

Conclusions

Our Olympian studies confirm crucial factors for talent development along the developmental stages. In different countries different factors were reported as more crucial for success of the STEM Olympians and their subsequent productivity. However, there were some commonalities. The crucial factors commonly found were:

- Early recognition of STEM talent and conducive home environment;

- Specialized challenging programs for developing strong STEM foundations and opportunities to participate in STEM activities and competitions during the schooling period; and,
- Strong motivation and efforts on the part of the Olympians for success throughout the developmental stages.

Developmental trajectory of STEM talent starts early [13, 31, 44]. Since early recognition of STEM talent by parents is crucial, more attention needs to be paid to the STEM-talented children from socioeconomically disadvantaged families. In addition, many STEM-talented students might still have negative experiences in their schools due to lack of respect for their talents and lack of challenging programs. In this environment, Olympiad programs and competitions are essential for developing STEM talent of youths outside of their schools. Gender gaps still exists in most countries. Female students need more support and encouragement from teachers and parents for participating in STEM-related activities and competitions.

When our studies were underway, we were not aware of the built-in bias among psychologists and educators against competitions. Alfie Kohn's [26] book "*No contest: The case against competition,*" gained national and then international prominence. His book focused on extrinsically- structured competitions, and he assumed that competitions were based on aggression and incompatibility. However, the book had a chilling effect for researchers doing competition studies. Marta Fulop (Hungarian Academy of Sciences) saw our publications as a significant blowback against this bias [19]. She found very little empirical evidence to support Kohn's [26] book. Our data-driven studies provided the support she needed to fight back.

Limitations

None of these international studies assembled control groups to bolster their claims of increased productivity for their academic Olympians. The U.S.S.R. initiated the Olympiad competitions in 1934 without any thought of including control groups, and the nations that have adapted these programs over the next decades have followed the same framework. The goal was identifying talent within the STEM domains and then to nurture it for the good of the state.

How many of the thousands of Olympiad participants should be recognized and selected for advanced training? The Olympiad competitions limit the numbers to only 20 individuals for most nations, and then to only six for the yearly international competitions. Such drastic cut-offs obviously miss many talented STEM high school students. The principal investigators for our Olympiad studies acknowledge this shortcoming. But there is a cost for increasing the numbers selected, and governments find it hard to justify this cost when their schools are supposed to be the main pipelines for STEM talent.

Another limitation of these studies concerns women and minorities that are underrepresented in the STEM professions in all the countries that joined us in this project. This is an issue for the people that run these Olympiad programs. Our studies were done by researchers not connected with the programs. Consequently, we can only communicate these concerns to the policy makers running the programs.

Our studies are retrospective by design. We asked the Olympians and their parents to remember their childhood and share with us how their talent was developed. Much of the information we collected concerned factual matters that were verified. But some involved critical incidents that had consequences for the Olympians and their parents. One limitation of this approach is that maybe the memories of the adult Olympians or their parents are not accurate.

The final limitation concerns the "losers" of these competitions. Since there are so many participants and so few winners is it fair to the overwhelming number of participants who do not win? Every student that enters the competitions must gain some advanced-domain knowledge. Some students gain a great deal of subject matter, while others just gain some extra knowledge beyond what is already available in their high school STEM courses. *However, is learning such advanced knowledge ever a liability?*

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