

More Than a System: What We Can Learn from the International Mathematical Olympiad

Mark Saul

Brigadoon

The northern European sky is often ambiguous. Patches of intense blue alternate with lowering grays. Fog conceals the landscape, lifting to reveal sky and water, then descending like a huge curtain. An enormous glass wall, one side of a hotel dining room, highlights the drama of the sky over the North Sea in the German city of Bremerhaven.

The jury of the 2009 International Mathematical Olympiad (the IMO), representatives of 104 countries, trickles in. The conversation reveals a community coming together, a community that, like the fabled Scottish village Brigadoon, comes to life once a year, for just ten days. Old friends greet each other, fill each other in on personal news, on prospects for their team, on the uncertainties of international travel. They sort themselves by language: English, French, Spanish, Russian, Chinese, and many smaller communities. It is a peculiarity of today's political geography that official languages are typically shared by two or more countries.

The full jury meets the next morning to decide on the problems to be set for the students. The discussion ranges from mathematics to pedagogy to the art of problem solving. Sequestered (by tradition) from the students, who are housed twenty miles away in Bremen, they look for problems that will cover a range of levels of difficulty and a variety of mathematical topics.¹ The problems must not favor routine methods studied in the school systems of participating countries. They must be true problems, not exercises.

Mark Saul is director of the Center for Mathematical Talent at the Courant Institute of Mathematical Sciences and an associate editor of the Notices. His email address is marksaul@earthlink.net.

¹See <http://www.imo-official.org/problems.aspx>.

The discussion is in earnest. Not only must each team be treated fairly, but also each student must get something out of participation. So the problems must have a certain difficulty—and a certain significance. The choices are not easy ones to make.

The Beauty Contest

A system, not quite an algorithm, emerges from the chaos of opinion. Representatives rank the problems not just by difficulty but also by “beauty”, a bit of ironic language that acknowledges a measure of arbitrariness in the judgments. Problems can be OK, pretty, gorgeous, and so forth. Delegates have observed that even these terms are “politically correct”. “OK” is more like homely, “pretty” is just “plain”, and so on. Diplomacy reigns throughout.

Indeed, for an international body, there is little contention. The lion and the lamb are equally powerful, mathematically. Historically, disagreement arises only on mathematical issues or on levels of difficulty.

And, occasionally, even on honesty. Over the years there have been just a few incidents of dishonesty and also of incorrect accusations of dishonesty. We hear that members of this team all gave the same unlikely solution for problem A. Members of that team visited the restroom too often. A journal in one country had a problem similar to problem B or one that gave a hint for problem C. Unfortunate, and requiring a most delicate sort of diplomacy. Enjoyment of the competition and fulfillment of its goals depends on people working together to achieve these goals. In making your team as excellent as possible, you are working toward a common goal. In making it merely look better than another team, you are working just for your own.

The search for problems is thus a process of

achieving consensus.² The debate touches on numerous issues in the field:

In problem D, you can write down all the coordinates, and then it's an unpleasant but routine matter to compute the lengths of the two segments in question. I'm too old to do this, but for a student who sees it, the solution becomes tedious and routine. On the other hand, the official solution, classic and synthetic, is very nice. The student who chooses this method will not suffer.

Motion that we start by choosing the easy problems. Good easy problems are the hardest to find.

Query: Our delegation would like to hear comments on the content of problem E. What is the significant mathematics in this problem?

Some of these problems are harder than they look. Problem F involves geometry, which is always difficult. Weaker students will fatuously chase angles. Motion to label Problem F "medium" rather than "easy".

Problem G falls to a technique which is standard in our curriculum. I'm not sure this is best, either for our students or for others. Motion to strike problem G.

The jury eventually reaches consensus. The significance of the entire event hinges on this consensus, a different significance for each audience. The participants themselves mostly find it fun and challenging and enjoy being with peers having similar interests, working on tasks involving just those interests.

Ripples

But, like a stone dropped in a pond, the ripples of the event have wider, albeit less intense, impact beyond that on the students gathered in Bremen. John Webb is the secretary of the IMO Advisory Board and has worked on mathematical competitions in South Africa for more than thirty years: "The IMO had a profound effect on our national

mathematics scene. Our Olympiad used to be severely elitist. Entering a team in the IMO stimulated the creation of a broad-based talent search, which in turn increased the number of students taking part in the national Olympiad. This change was influenced by the need to find students to represent the country in the IMO."³

József Pelikán from Hungary is a veteran of many IMOs and has been chair of the IMO Advisory Board for the last eight years: "Perhaps numbers alone will not tell the story. In some countries even the very idea that math can be a topic for a competition and not just an endless source of drill is such a novel one that it drives change. This phenomenon would not be easy to summarize in a research report."

Here, at the epicenter of IMO activity, I found evidence of some of the ways that Pelikán's observations played out. The clearest picture, in an event like this, is of the peaks of achievement: the students who are most successful. An examination of their success can yield a broader picture of how we can build and maintain systems that discover and nurture this sort of talent.

Omer Cerrahoglu

One of these is Omer Cerrahoglu. Born in Istanbul but educated in Romania, fourteen-year-old Omer distinguished himself in a chain of local and regional contests and was among the youngest students at the 2009 IMO, where he received its highest honor, a gold medal.

I first heard of him from a Romanian mathematician friend in the United States, then again from Radu Gologan, the leader of the Romanian team. Their comments carry weight. Romania is among the leading countries in the IMO. The very first IMO was organized by Romania, and they have consistently done well—better than the size of their population or their economy would predict—on these events. So the Romanians have seen it all, and if they say that this student is outstanding, I pay attention.

Gologan gave a firsthand description of Omer's thinking style: "Omer is intuitive. Like Ramanujan, he looks and sees and writes it down—then later he proves it. He has gotten many classical results by himself. I've seen him solve a problem about the altitudes of a triangle without knowing what an orthocenter was. 'The altitudes must intersect, and the intersection has this and this property', he reasoned, and eventually solved the problem."

But at what cost? Can a fourteen-year-old personality support a mind like this? Gologan

²A more detailed account of the process of selecting IMO problems can be found at <http://www.win.tue.nl/~wstomv/publications/imo2002report.pdf> or at http://www.maths.otago.ac.nz/home/schools/gifted_children/olympiad.pdf.

³For more information about the South African system, see, for example, Mark Saul, "A distant mirror", *AMS Notices*, April 2001, at <http://www.ams.org/notices/200104/comm-saul.pdf>.

answered the question before I asked it, starting with an oxymoron: “He is an extremely normal kid. His colleagues love him. In the last few days of preparation, we have a psychologist interview the students about handling the competition emotionally, how to remain calm, to allow their minds to function under pressure, and so on. This psychologist had not seen a child with Omer’s range of intellectual and emotional maturity. Her comment? ‘If Omer didn’t exist we would have to invent him’.”

The important point is that Romania’s system of talent development was able to support Omer. He lives in the north of Romania, not in the capital. Because he went to school in Romania, he entered an Olympiad. The system thus “discovered” him, then provided him with peers and mentors who would encourage and reward his achievement. This is a mature system, typical of those in eastern Europe, which has been described often before.⁴

Raul Sarmiento

And even he was not the youngest in history. Terry Tao was slightly younger in 1986 when he wrote his paper for a bronze medal. He was ten, then had a birthday that week, so he was barely eleven years old when he received the bronze medal.

Omer was also not the youngest student at the 2009 IMO. That distinction belonged to eleven-year-old Raul Arturo Chavez Sarmiento from Peru, who won a bronze medal. Whereas Omer is the product of a mature and robust system, Raul has been served by a successful nascent system. Like Omer, Raul lived in a city far from the capital. His gifts showed up on the national Olympiad, so one of the schools in Lima gave him a scholarship, and the rest is history.

Maria de Losada, the Colombian team leader, is also one of the prime movers of the IMO. She started the program in her own country and leveraged her success there to bring virtually the entire Latin American region into the IMO. Losada comments: “The Peruvians have been working very hard. Their Olympiad is supported by their ministry of education and reaches virtually all the schools in the country. Peru has a population of about twenty-five million, with about three million students in the national Olympiad. The Peruvians get a larger number of students, and a higher percentage of students, to participate in their national Olympiad, than many countries with a similar population.

⁴See Mark Saul, “Mathematics in a small place: Notes on the mathematics of Romania and Bulgaria”, in *AMS Notices*, May 2003 (at <http://www.ams.org/notices/200104/comm-saul.pdf>) or Saul, “Love among the ruins: The education of high-ability mathematics students in the USSR”, *Focus*, Vol. 12, No. 1, February, 1992.

“In Latin America, we work with each other and learn from each other. More than most other regions, we are unified by language, history, and culture. In 1985 UNESCO helped us initiate the Ibero-American competition, which continues to this day. The IMO in Argentina (1997) brought us still closer together. The organizers of these events were able to attract coordinators [question graders] from all over Latin America, who learned from each other about the mathematics and logistics of the Olympiad. Our Colombian team has trained with teams from Venezuela, Ecuador, Costa Rica, Panama, and Peru.

“One of the keys is an early start. We have found the most success when students and teachers learn early about competitions in mathematics. Another is the forging of a community which includes both the mathematicians and the teachers. For example, in Brazil, one of the national Olympiads is funded by the government, which pays professors at the public universities to develop and grade the contests.

“Difficulties? One difficulty we find, particularly from the smaller countries in our region, is that students don’t see themselves as potential winners in the IMO. They’ve triumphed in the national contests, but when they meet students from larger countries, or from countries with older and deeper traditions, they are intimidated. They tend to lose confidence and frequently don’t do their best. We see this time after time and are not sure how we can help.”

Systems Make the Difference

As I talked with IMO students and coaches, the importance of systems of support emerged. A mind like Omer’s or Raul’s is a great gift. Where do such talents come from? How do we find them? The answer seems to lie in large-scale systems of support. Had Omer been born in Senegal, had Raul been born in Peru forty years ago, their gifts would very likely have gone unnoticed. The systems serving them made possible the emergence of their gifts.

The Romanian system is old and robust. The Peruvian system is younger but sturdy. In other regions of the world, the system of talent development in mathematics is much more fragile.

African countries, for example, are not well represented at the IMO. Just five African countries (out of about fifty) had a team enter prior to 2005, and the number is growing only slowly. In 2009 two “new” countries sent teams, and two more sent observers (a prerequisite to being invited in the next year). Similar conditions hold in the Middle East.

Building Capacity

How does a country build the capacity to field an IMO team? And how can it use the opportunity to build such a team to stimulate wider and deeper interest in mathematics? One model effort has

been launched by Saudi Arabia. The Saudis have fielded an IMO team for several years but have not been satisfied with its achievement. Rather than sending a team in 2009, they sent observers, who have been looking at best practices for team development throughout the world.

One of these observers was Dr. Abdulaziz Salem Al-Harhi, the IMO Project Manager for Saudi Arabia: “We are concerned about the standard of mathematics in our schools on the precollege level. We see IMO participation as a motivation to stimulate learning and appreciation of the subject in our country. Our mission here is supported by the Mawhiba Foundation, headed by the king.”

Al-Harhi described his program. They use an SAT-style test, taken widely throughout the country, to retain a broad base yet identify the most promising students. These students are urged to take a national Olympiad test. The winners are then trained and a team identified from among them.

Al-Harhi said: “Selection and training are the key. We have visited a number of countries and invited experts in training Olympiad students to our country from around the world. Not only will they train our team, but they will give us ideas about how we can do this ourselves in the future.

“Good mathematics students in our country tend to go into medicine or engineering, fields in which their contributions, and their monetary rewards, are much more visible to the public. We are hoping that the IMO will help us change this public view of mathematics.”

Even well-established teams give evidence that their systems work. The Faroe Islands, a part of Denmark, are in the North Atlantic, more than one hundred watery miles from the next center of population. Yet twice in the history of the IMO, students from the Faroe Islands were chosen to represent Denmark in the IMO. It was a system of talent identification that allowed this: a local teacher got the students to enter the national contest.

The Loftiest Peaks

So systems catch talent. But do they support it? Nurture it? Bring it to fruition? Or is success in mathematics solely the result of determined individuals?

The 2009 IMO was special: it was the fiftieth event of its kind.⁵ The first IMO was initiated by Romania in 1959, and early events were attended only by countries of the Eastern bloc at the time. The first Western country (Finland) participated in 1965, and the United States joined in 1974.⁶

With the support of the John Templeton Foundation, the German organizers of the 2010 IMO brought six Fields Medal winners, all IMO alumni,

⁵See, for example, <http://imo.wolfram.com/facts.html> and <http://imo.wolfram.com/morefacts.html>.

⁶See <http://www.imo-official.org/results.aspx>.

to speak with the students. They spoke both formally and informally, and their words give a picture of a community, by now international, that creates systems, by now global, that produce mathematics.

Bollobás

Béla Bollobás was at the first three IMOs, 1959–1961: “It was completely different then. In those days, Hungarians couldn’t travel, and even a trip to neighboring Romania was a treat. I was very excited to meet so many students from other countries. It was great to know that being among the top in Hungary also meant being among the elite young mathematicians in the world—or at least the Eastern bloc.

“My mathematical talent showed pretty early. Until I was nine years old, my father, a doctor, wanted me also to be a doctor. I have no idea how, but father managed to persuade a medical instrument factory to produce tiny toy medical instruments for me to play with, so that I’d long to use the real instruments later. But when I was nine my father had a chat with my teachers in school, who told him that I was rather good at maths. Soon I was some years ahead of my peers, and later this lead stretched to about four years. When I went to the university, I unofficially knew the mathematics of the first three or four years. I took all the courses, and I loved them, even though I knew most of the material already.”

Bollobás here was putting a positive spin on a comment I had heard from many much younger students at the IMO: school mathematics was boring. These minds need more of a challenge.

Bollobás continued. “In school I did not have to pay any attention to the maths lessons. My mathematical inspiration came from private lessons from an excellent lecturer, István Reimann, at the University, and from *KöMaL*, our Hungarian student journal. Reimann guided me in various areas of mathematics. We always had a ball talking about maths. In *KöMaL* I could read about what my peers were doing mathematically, even if I hadn’t met them. And this journal gave the students plenty of motivation, because they published the best solutions. That seems to be an ideal system. In some ways, this is better than the IMO, since at the IMO you get no credit for giving two different solutions, or for a generalization. Working for *KöMaL* was much closer to research.”

Gowers

Timothy Gowers is tall and thin, with a shock of white hair. He speaks slowly and deliberately—and one wants to hang on to his every word. He is a great communicator. I enjoy his writing. Brisk and terse, it is as effective as, but completely different from, his speech.

One of Gowers’s remarkable contributions to our intellectual life does not concern mathematics itself but “doing” mathematics. He has proposed a

Some Achievements of Mathematicians Mentioned in this Article

Béla Bollobás

IMO 1959 Bronze Medal
IMO 1960 Gold Medal
IMO 1961 Gold Medal

Timothy Gowers

IMO 1981 Gold Medal
Fields Medal, 1998

László Lovász

IMO 1963 Silver Medal
IMO 1964 Gold Medal
IMO 1965 Gold Medal
IMO 1966 Gold Medal
Wolf Prize, 1999

József Pelikán

IMO 1963 Silver Medal
IMO 1964 Gold Medal
IMO 1965 Gold Medal
IMO 1966 Gold Medal

Stanislav Smirnov

IMO 1986 Gold Medal
IMO 1987 Gold Medal
Fields Medal, 2010

Terence Tao

IMO 1986 Bronze Medal
IMO 1987 Silver Medal
IMO 1988 Gold Medal
Fields Medal, 2006
MacArthur Fellowship, 2006

Jean-Christophe Yoccoz

IMO 1973 Silver Medal
IMO 1974 Gold Medal
Fields Medal, 1994

Günter M. Ziegler

IMO 1981 Gold Medal

Radu Gologan

IMO 1970 Silver Medal
IMO 1971 Silver Medal

Sources:

<http://www.imo-official.org/hall.aspx>

http://en.wikipedia.org/wiki/Wolf_Prize_in_Mathematics

<http://www.infoplease.com/ipa/A0192505.html#axzz0zEgA62dW>

http://en.wikipedia.org/wiki/MacArthur_Fellows_Program

form, or forum, called “polymath”, in which anyone who cares to can contribute to the research of a mathematical problem. The structure of the form (it does have a structure!) can be viewed⁷ at <http://gowers.wordpress.com/2009/01/27/is-massively-collaborative-mathematics-possible/>.

But Gowers did not talk with me about his polymath idea. He talked more directly about the IMO: “I was not a prodigy. In school, I knew that I was good at maths. But I didn’t know what I was capable of until I came to the IMO.

“The IMO was a positive experience, a life-changing experience. For the first time I realized that I might actually be good enough at mathematics to be a mathematician. Had I not gone to the IMO, I would still have gone up to Cambridge to read maths. Having got there, I would have found other students who were clearly better than me. Without the confidence I gained at the IMO, I might

⁷For another of Gowers’s contributions to the problem-solving community, see <http://www.tricki.org/>. See also <http://numberwarrior.wordpress.com/2009/03/25/a-gentle-introduction-to-the-polymath-project/>.

have been demoralized. But as it was, the IMO had given me a faith in my ability that could survive the times when I did less well relative to my peers. So I persisted.

“By the way: I also know some people for whom it was not a good influence in their lives, people who were unable to make the transition to research-level mathematics.

“The IMO problems are different from mathematical research. In doing research, one can actually change the problem one is working on, shape it, make it more tractable and one’s efforts more fruitful. IMO problems are fixed.”

József Pelikán had a different metaphor for this point: “IMO problems are like animals in a zoo. Mathematical research is like studying animals in the wild.”

Is it the competition at the IMO that is a driving force in mathematical creativity? Is it rivalry, or even just communication, with one’s peers that makes people want to explore mathematics?

“That’s part of it,” explained Gowers. “But not everything. Let’s put it this way. Suppose I went to prison for some crime. Suppose I were allowed access to a library, to the tools of mathematical

research, but not to my colleagues. In that situation, I do not know whether I would still do mathematical research. The subject is intrinsically interesting, and there are certain problems I would love to solve, but solving problems requires a great deal of dedication: the reactions of other mathematicians are one of the main reasons I continue with it.”

Yoccoz

Jean-Christophe Yoccoz addressed this subject in a slightly different way: “Is mathematics useful? Usually, but I don’t care. Still, as a Platonist, I have the feeling that when you discover something in mathematics, you are discovering something for real, something that exists in the real world. And that gives me satisfaction.”

Yoccoz, like Tao and Bollobás, knew early that he would be a mathematician. “I came from an academic family. My father was a physicist, my mother a translator, so I had a good idea that one could make a career as an academic. I discovered my love for mathematics very early, and it still motivates my work.”

Tao

Terence Tao’s particular brand of intellectual enthusiasm showed through in one of his first remarks: “The IMO was one of the best times of my life. A week’s vacation, and all you have to do is answer six simple questions.”

Did the IMO influence his decision to become a mathematician? “My course was set on mathematics quite early. The IMO experience meant something else to me. First of all, it was fun being with other students who enjoyed solving hard math problems. I don’t remember any particular bit of mathematics I learned at the IMO that proved significant later on. It’s not like that. But the habits of problem solving—taking special cases, forming a subproblem or subgoal, proving something more general, and so on—these became useful skills later on. It’s worth teaching students those skills through Olympiad work.

“But serious mathematical research involves other skills: acquiring an overview of a body of knowledge, getting a feeling for what sorts of techniques will work for a certain problem, putting in long and sustained effort to accomplish something. These are skills I acquired later, through other means. I would not want students to think that IMO-type problems are all there is to mathematics. I mean, the twin primes question [the existence of infinitely many twin primes] seems like an Olympiad problem if you look at it shallowly. Even getting one pair of large primes is an achievement, an achievement which can take more than three hours.”

As it happens, Tao has used Gowers’s polymath concept to give us an idea of how IMO problems can grow into more serious mathematical research. At <http://terrytao.wordpress.com/2009/07/20/imo-2009-q6-as-a-mini-polymath-project/>, he has made a polymath project out of problem 6 on the 2009 IMO, the “grasshopper problem”. This turned out to be one of the most difficult problems ever posed at an IMO, fully solved by only three students.

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Smirnov

So Tao is using Gowers’s idea to show us how the IMO experience can grow into a more serious mathematical endeavor. Stanislav Smirnov addressed this relationship as well, in his remarks to the students:

“Mathematics research has become a truly collaborative effort, in that it is different from the actual IMO competition. It is much more interesting to work on problems together, and sharing ideas is always a rewarding experience. And in one aspect mathematical research is much like the IMO—both are truly international.”

Smirnov concluded with a personal welcome into the mathematical community: “I hope that many IMO participants will go on to become mathematicians, and that we will meet again.”

Lovász

Günter M. Ziegler, a much-honored Berlin mathematician, won an IMO gold medal in 1981 and acted as the personable and articulate host of the awards ceremonies. On stage, he asked László Lovász how much he earns from being president of the International Mathematical Union.

Lovász replied, “The amount is actually negative, because I forget to submit travel bills.”

“And do you get bribes?” asked Ziegler, joking.

Lovász grinned: “Well, not exactly bribes. But if you want to have a lower Erdős number, maybe you can advertise that you will reward someone with a lower number to write an article with you....”

This idea is not likely to be very influential. So Lovász then gave a more serious talk about how ideas spread through the mathematical community and how mathematics itself gives us tools to study that spread.

His talk was about graphs—huge graphs, such as the Internet. “Just as a crystal is a huge network of atoms, so the human brain is a network of neurons. And the same is true of human society as a whole.

“As one gets older one sits more with other scientists from different areas. And more scientists are using networks to describe what they do. Historians sometime call this the ‘network of human interactions’. And history itself—not just of mathematics—may depend on how religion, ideas, disease, news, and so on spread through these networks. So it is important to look at their structure. Understanding large graphs is a very important task for mathematics.

“A lot depends on asking the right questions. Does the Internet have an odd or even number of nodes? This is probably a meaningless question.



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We don't know the answer, and the Internet itself is not well defined. But if we ask: How dense is the graph? Or: What is the average degree of a node? This is a very useful piece of information to know about the Internet.

"Is the Internet connected? This is a tricky question. The answer is probably 'no'. Somewhere there is a bad router and an unhappy group of people who don't have a connection except among themselves.

"But we can shape this question to have still more importance. Suppose there is an event, say an earthquake, which severs connections between the old and new worlds. Will the Internet still be connected? Or, in the bad old days, were there 'socialist' and 'capitalist' Internets, with no connection between them? These questions are meaningful, but interesting only if asked in the right way. What we really want to know is if the Internet decomposes into big parts.

"When I was young it looked like mathematics was going to decompose into just such big parts. Now there are many more connections between these parts. So my advice to young mathematicians is to be prepared to go and learn some area of mathematics which you thought you were not interested in. They might impose themselves on you, and you should be happy about this. It might lead to interesting developments."

Pangea

I understand Lovász to be saying that the mathematical network, the mathematical community, is somehow strongly connected, with more connections appearing all the time, like the continents drifting together to form the complex geologists call Pangea. It is this community that has appeared, almost magically, on the north coast of Germany. It is these close connections that allow the IMO community to exist, coming together only once a year. It is these connections, too, that create the systems—local, national, and regional—that discover and support new talent, young people who rejuvenate and extend the system that supported them.

So it is more than a group of individuals that creates our mathematics: it is a system. And it is more than a system that keeps itself going: it is a community that forges the system.