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ORIGINAL PAPER

Mathematical competitions in Africa: their prevalence and relevance to students and teachers

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Abstract

Mathematical competitions feature in most developed countries as a part of the secondary school experience, but to a lesser extent in developing countries. In this paper we investigate how widespread these competitions are in Africa, both historically as well as currently, focussing both on national Olympiads and on the participation of African countries in competitions beyond their borders, such as the continent-wide Pan African Mathematical Olympiad and the global International Mathematical Olympiad. Since we could not find a consolidated source of information on African competitions, we include many details and links, hoping that this paper will serve as a valuable starting point for future investigators. Next, we present some survey findings on the attitudes towards and experiences of mathematical competitions, both from the perspective of teachers in secondary schools as well as from secondary school students, and whether these experiences have served to improve or degrade their perceptions of mathematics in general. Among other results, we find that teachers view their students' participation in mathematics competitions as being important, with the biggest barrier to participation being that there are not enough competitions at appropriate levels available, and that students enjoy mathematics competitions and are more likely to pursue a STEM career because of them. Finally, we present some suggestions on how this research may be taken further, and on how the state of mathematical competition culture in Africa may be improved.

Keywords Africa · Secondary school · International competitions · Mathematical competitions · National competitions · Mathematical culture

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1 Introduction and paper outline

National and regional mathematics competitions feature in most developed countries, as shown for instance on the Art of Problem Solving website's Contest Collections.[1] These competitions help to increase interest in and enjoyment of mathematics among young people, thus contributing to the public perception of mathematics and a more mathematically literate adult population over time. However, the same prevalence of competitions and perception of mathematics is not necessarily found in developing countries; in this paper we investigate the history, prevalence, and state of mathematics competitions in Africa, what their effect is on the perception of mathematics by their participants, and how valued they are by students and teachers.

Our guiding questions were the following:

1 https://artofproblemsolving.com/community/c13_contests.

- Does each African country have a national mathematical competition, and if so, for how long has it been running and how regularly does it take place?
- Which international and regional mathematical competitions do each African country take part in?
- What are the history and statistics of the Pan African Mathematical Olympiad?
- At which ages do mathematical competitions start in each African country?
- Why do African countries perform so poorly at the IMO (the largest mathematical competition in the world)?
- How important are mathematical competitions to African teachers and students?
- Do mathematical competitions have positive or negative effects on their participants and organisers?
- Do mathematical competitions serve to improve or to degrade the public perception of mathematics?

The paper is organised as follows:

In Sect. 2, we give some background and history of the Pan African Mathematical Olympiad (henceforth abbreviated as PAMO) and national and regional mathematics competitions in African countries.
In Sect. 3, we detail more of the culture of mathematics competitions in Africa and African countries' performance in the largest mathematics competition in the world (the IMO), as well as possible ways in which the situation can be improved.
In Sects. 4 and 5, we examine survey responses to gauge the importance of mathematical competitions to teachers (Sect. 4) and students (Sect. 5), including some statistical analyses. We also examine the effects of these competitions on their experience of school mathematics and mathematics in general.
Finally, in Sect. 6 we present some concluding remarks and opportunities for future research on these topics.

2 Background of African mathematical Olympiads

The most important Olympiad on the African continent that spans across nations is the Pan-African Mathematical Olympiad,[2] although some national competitions predate PAMO. Therefore, the inauguration and history of PAMO is discussed first, followed by national and regional contests, and lastly participation of African countries in non-internal contests are discussed.

In the process of putting this article together, a spreadsheet database[3] (Labuschagne) was created for African Competition & Olympiad Statistics with more details on student participation numbers, school participation numbers, information about whether competitions have sponsors, history of competitions wherever possible, etc., as well as a summary of International Mathematical Olympiad (IMO[4]) and PAMO participation and awards by African countries, with a summary of the data being presented in this section.

This database was developed since the authors could not find an existing summary or study about the various contests across Africa, although a very brief description of contests in some countries was found in a report (Developing Countries Strategies Group International Mathematical Union, 2009) to the John Templeton Foundation titled "Mathematics in Africa: Challenges and Opportunities". However, this report mostly focused on mathematics education in primary, secondary and tertiary institutions and only as an afterthought mentioned some information about contests. The authors therefore tried to track down information on various contests from sources such as their official websites, contest booklets, newspaper articles mentioning contests, and the question included in the survey asking participants in which contests they have participated.

More information about this spreadsheet database is available by contacting one of the authors; we hope that it will be updated and expanded upon to sketch a more detailed picture.

2.1 Inauguration of PAMO

According to information available on the PAMO website, which is hosted as part of the African Mathematical Union website, the first PAMO took place in Morocco (Rabat) in 1987 with 7 participating countries after the 2nd African Mathematical Union (AMU) Congress of Mathematicians instituted the AMU Commission on PAMO a year earlier. The Commission's responsibility was to organise PAMO each year, running it in an African country willing and able to host it, and to expand the competition to all of Africa. The second PAMO took place in Nigeria in 1989 with 9 participating countries, followed by the third PAMO in Kenya in 1991 with only 3 participating countries.

2.2 History of PAMO

The African Mathematical Union website[5] has full results of the PAMO from 2004, partial results for the 2002 and 2003

[2] https://www.africamathunion.org/AMU-pamo-official.php.

[3] https://docs.google.com/spreadsheets/d/1iROrOPyLYwM75V0-8JsfCKZ6DjpaqR6bdJZHEp8K0sM/edit.

[4] http://imo-official.org/.

[5] http://africamathunion.org/AMU-pamo-official.php.

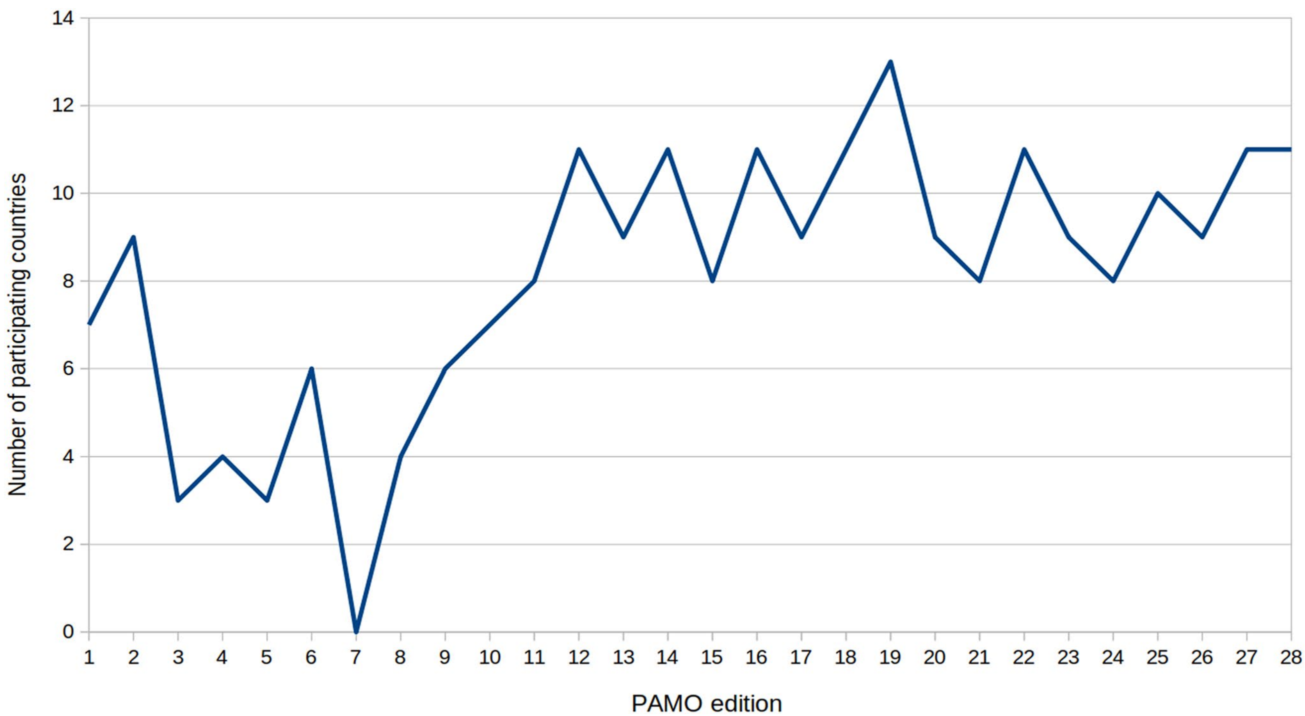

Fig. 1 Line graph of participation numbers per PAMO

PAMOs, a list of countries who attended the 2000 and 2001 PAMOs, and the timeline of host countries. Furthermore, a list of countries who attended PAMO before 1997 is available in (Ilori, 1997), but it does not list which countries attended which editions. Finally, (El Yacoubi, 2008) contains some details of the history of the PAMO. To follow is a summary of PAMO over the past three decades.

From 1987 to 2020 there were in total 28 editions of PAMO. However, among these the 1996 PAMO in Uganda is counted as the 7th edition of PAMO even though it did not take place, being cancelled at the last minute. Furthermore, there was no PAMO held in the years 1988, 1990, 1992, 1999, 2011 (postponed to 2012 due to the Arab Spring), 2014 (SA was asked to host but due to already hosting the IMO the organizers deemed it unfeasible) and 2020 (postponed to 2021 due to COVID-19). The longest consecutive run of PAMOs was 11 from 2000 to 2010 and the second longest run was 5 from 2015 to 2019.

There have been 12 different host countries of which Morocco, Nigeria and South Africa have each hosted 4 times. This accounts for almost half of the PAMOs. Furthermore, strangely it has happened at least six times (almost a quarter of the times the Olympiad has taken place) that the host of PAMO did not participate in the next edition, happening at least with Kenya 1991, Morocco 1998, Algeria 2005, Senegal 2006, Senegal 2016, and Kenya 2018.

In total 31 out of 54 African countries have participated in PAMO, but 9 of them have not participated in the last 10 years. The record for the greatest number of countries at a PAMO is 13 (South Africa in 2009). A tally of the number of countries participating per year has been summarized in the line graph in Fig. 1.

The countries that participated in PAMO over the last 10 years are classified in Table 1 based on how regularly they participated. The countries are sorted first by number of participations and then by time relevance, which regards more recent participation as more important.

Table 1 Countries participating in the last 10 years

Regular	Irregular	New	Once-Off
South Africa (8)	Morocco (4)	Botswana (4)	Egypt
Tunisia (8)	Kenya (4)	Rwanda (1)	Niger
Nigeria (7)	Ghana (4)		
Côte d'Ivoire (6)	Burkina Faso (4)		
Tanzania (6)	Uganda (3)		
	Togo (3)		
	The Gambia (3)		
	Malawi (2)		
	Mali (2)		
	Senegal (2)		
	Benin (2)		
	Algeria (1)		
	Zimbabwe (1)		

Table 2 Overview of South African contests

Event	Founded	Grades	Resources	Students	Schools	Entry Fee	Sponsors
SAMO	1966	8–12	Yes	83,238	1060	Yes	Yes
UCTMC	1977	8–12	Yes	7142	158	No	Yes
SAMC	1986	4–7	Yes	81,602	630	Yes	Yes
SAMTC	1990	8–12	Yes	855	–	No	Yes
UPMC	1991	6–11	Yes	4000	–	Yes	No
HMC	2000	5–7	Yes	34,538	–	Yes	Yes
BM	2016	4–7	Yes	4300	25	Yes	Yes
WMC	2018	4–12	Yes	4967	90	No	Yes

Over the last 10 years only five countries have been regular in their attendance of PAMO by participating in 75% or more PAMOs. PAMO cannot grow if most countries will keep falling into the category of irregular countries. Irregular countries are countries who have participated in 50% or less PAMOs over the past 10 years. There are two exceptions made: the first is countries who are new and have attended every PAMO since they joined for the first time, and the second is countries who only participated once in the past 10 years and at most once in the 10 years prior.

The countries that have not participated in the past 10 years but participated only between 2000 and 2010 are the Central African Republic (1), Mauritania (1), Burundi (2), Namibia (2), Lesotho (3), Cameroon (5), Mozambique (5) and Eswatini [Swaziland] (7). Furthermore, Guinea only participated before 2000, but it is unknown how many times.

2.3 PAMO-G

The PAMO-G (PAMO for girls) was introduced in 2015 in Nigeria. According to the organisers, this was to address the heavy gender imbalance in the PAMO (as is present in most mathematics competitions) by encouraging African countries to intentionally train girls, or else have their ranking at the PAMO negatively impacted. The team requirements for PAMO changed from being four students to being six students: at most three boys and at most three girls. Also, in addition to the medals that all students receive based on the ranking of their scores in the PAMO paper, the girls are also ranked separately and receive medals based on their performance in that ranking (so a strong-performing girl may receive two medals).

2.4 National and Regional Contests in African Countries

2.4.1 South Africa

South Africa has a rich history of mathematical competitions stretching as far back as 1966.[6] Table 2 gives an overview of eight of the national and regional competitions and Olympiads, which are organized by the South African Maths Foundation, universities, or schools.

These competitions are the South African Mathematical Olympiad (SAMO[7]) (Ncongolo, 2016, 2017, 2018) (Olivier E., Report on the South African Mathematics Olympiad, 1998, 1999, 2000) (Olivier E., South African Mathematics Olympiad Annual Report, 2008, 2009, 2010, 2011, 2012, 2013) (Ridley & Broere, Report on the South African Mathematics Olympiad, 1992, 1993, 1994) (Ridley, Report on the South African Mathematics Olympiad 1996, 1996), the University of Cape Town Mathematics Competition (UCTMC[8]) (Webb, The UCT Mathematics Competition Yearbook, 1987–2019), the South African Mathematics Challenge (SAMC[9]) (Olivier A., MASA Mathematics Competition 1992, 1993) (Olivier A., AMESA Mathematics Competition 1993, 1994, 1994, 1995) (Olivier A., Mathematics Challenge 1995, 1996, 1996, 1997), the Inter-Provincial Mathematical Olympiad (IPMO) now known as the South African Mathematics Team Competition (SAMTC[10]), the University of Pretoria Mathematics Competition (UPMC[11]) (Greybe, 1995), the Horizon Mathematics Competition (HMC[12]), Beyond Maths (BM[13]), and the University of Witwatersrand Mathematics Competition (WMC[14]). SAMO and SAMC are the official national olympiads for high school and primary school students, respectively.

Each of the competitions in Table 2 has taken place every year since its founding except for the UCTMC which was cancelled in 2020 due to COVID-19. The numbers given for

[6] http://sams.ac.za.www78.cpt1.host-h.net/history-promotemath-sams/.

[7] https://www.samf.ac.za/en/sa-mathematics-olympiad.

[8] http://www.uctmathscompetition.org.za/.

[9] https://www.samf.ac.za/en/sa-mathematics-challenge.

[10] https://www.samf.ac.za/en/assa-sa-team-competition.

[11] https://www.up.ac.za/mathematics-and-applied-mathematics/article/47663/up-mathematics-competition.

[12] http://hmc.org.za/.

[13] https://beyondmaths.co.za/.

[14] https://wmc.ms.wits.ac.za/.

students and schools are the average over the last 10 years. Each of these competitions has a website that features past papers and other information like past results; furthermore, some of them also publish annual report booklets. Most of them consist of multiple rounds and the formats range from multiple choice to numerical answers to essay type questions. In South Africa grades are usually split as primary school (1 to 7) and high school (8 to 12).

Apart from the competitions listed in Table 2, there are some which are organized as inter-school competitions with only a few schools and less than 100 participants. There are also events where a competition is written during a training programme; one such has been offered twice a year at UCT on Saturday afternoons over the past 30 years for about 150 students, and another has been offered for the past 25 years in the form of the Nautilus programme held four times a year on Saturdays at the University of the Free State.

Furthermore, there are also competitions which are organized by companies. Most notably, a newspaper named Die Burger started a competition in 2017 only available in the Afrikaans language with prize money much more than that available in the national olympiad. Although no past papers are made available, students experienced in IMO and PAMO who wrote these exams have complained that the quality of the question papers is low.

Lastly, the contribution of one individual, Professor John H. Webb, needs to be mentioned. Although from the above table, he was only the founder of the Inter-Provincial Mathematical Olympiad (now renamed the SAMTC) and has acted as the Director of the UCT Mathematics Competition since 1987, his influence stretched much broader. He was the driving force behind South Africa joining the IMO in 1992 and the PAMO in 2000 and served as secretary of the IMO Board from 2001 to 2012. The model he set up for the selection and training of the South African teams for IMO and PAMO is still used to this day. He was also the driving force behind South Africa hosting the IMO in 2014, which is still the only instance of an African country having done so. In 1971 he founded The Mathematical Digest, which was a quarterly magazine posted for free to high schools in South Africa until the end of 2014. This magazine was a collection of interesting articles, puzzles, challenges and general information of events and competitions taking place in South Africa and other countries (Webb, The Tenth Pan-African Mathematical Olympiad, 2000) (Webb, The Eleventh Pan African Mathematics Olympiad, 2001) (Webb, South Africa Scoops Maths Gold Medals, 2002) (Webb, PAMO in Maputo, 2003) and likely served as the influence behind South Africa having such a rich history of publishing information about competitions.

2.4.2 General discussion of other Countries

Unlike South Africa, where most mathematics competitions have dedicated websites with past papers, past results, some history of how and when they began, as well as how to participate, most other African countries do not seem to have such easily accessible information, with what we have been able to find being mostly in online newspaper reports. However, for a few countries some information is available either from a website or from someone involved with the competitions in the country who could cast a light on it.

In the following table we have organised the African countries based on how large or well established the maths competition activities there are (Fig. 2). For more information, including sources, please see the aforementioned spreadsheet and the following sources: (Gerdes, 1984),

- Those in the Well-Established category have national and far-reaching competitions which have been running stably for at least 10 years.
- Those in the Medium category have a national competition which is not old or large enough to be in the Well-Established category or have a large regional competition.
- Those in the Small category have one or two small local or regional competitions, perhaps only involving a few schools, used to have a national competition, or have a very new national competition.
- For those in the None Found category, no information about internal competitions could be obtained, whether through the survey sent out, through personal contacts, or through searching on Google in English, French, and Portuguese.

Furthermore, some countries of interest are Ghana and Nigeria,[15] which have regular mathematics quizzes on TV; these most likely help to popularise mathematics there.

2.5 Participation of African Countries beyond their Borders

Apart from PAMO and national and regional contests, some countries also participate in other contests. Most notably, some South African contests are open to participants from other countries in Africa. SAMO has regularly had participants from neighbouring countries Namibia, Botswana, Eswatini, Zimbabwe, and Lesotho, as well as countries further away such as Malawi and Nigeria. The South African Maths Team Competition has also tried to encourage the participation of teams from other African countries. The

[15] http://www.cowbell.ng/en/cowbellpedia/.

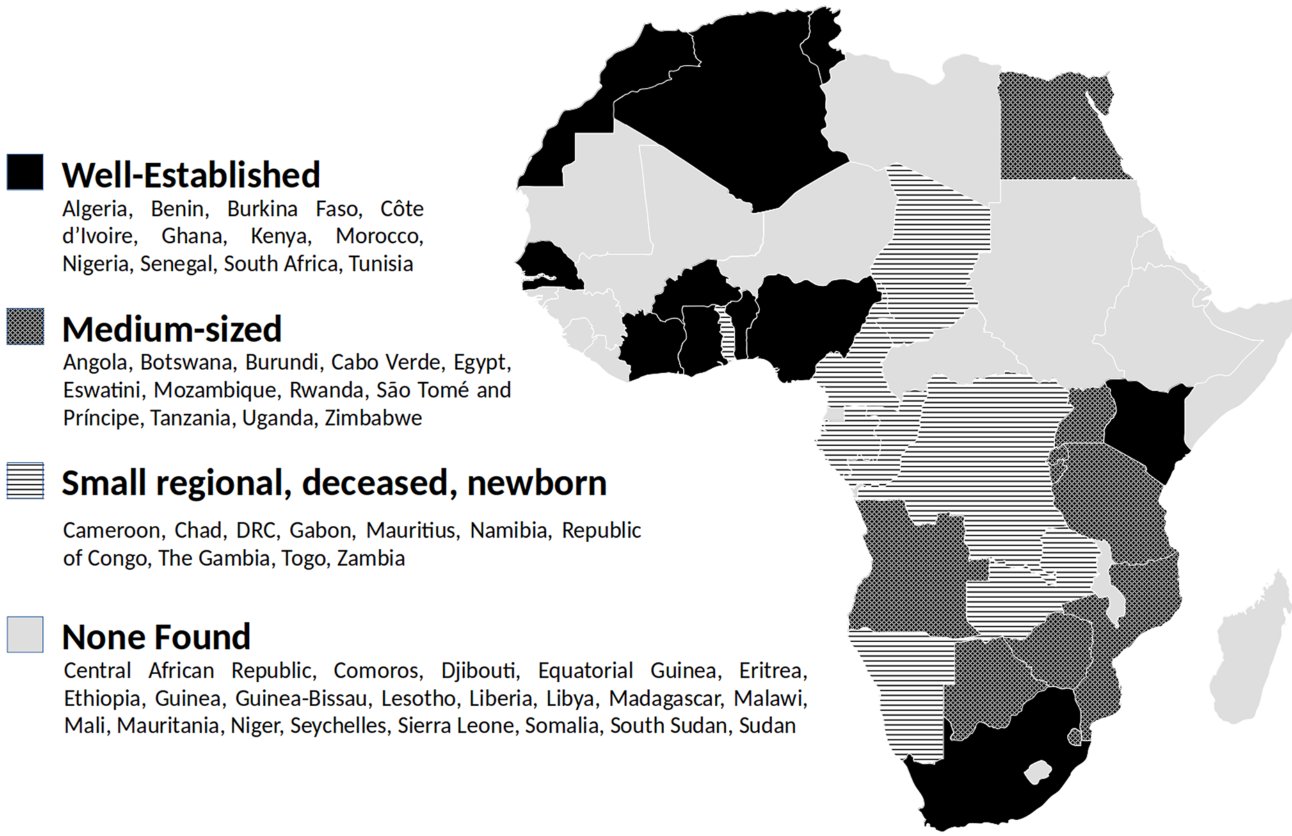

Fig. 2 Categorisation of African countries' mathematical competition development

Table 3 African participation in non-African contests

Event	Countries
Asian Pacific Maths Olympiad[a]	Côte d'Ivoire (2011) and Morocco (2020)
European Girls' Mathematics Olympiad[b]	Tunisia (2015, 2017, 2018)
Iranian Geometry Olympiad[c]	Algeria, Nigeria, South Africa
Mathematical Kangaroo[d]	Algeria, Egypt, Mozambique, Nigeria, Tunisia
Lusophone Olympiad	Angola, Cape Verde, Mozambique, São Tomé and Príncipe
Iberoamerican Math Olympiad	Mozambique, Cape Verde

[a] https://www.apmo-official.org/.
[b] https://www.egmo.org/.
[c] https://igo-official.com/?lang=en.
[d] http://www.aksf.org/.

University of Pretoria Mathematics Competition has participants from Namibia. The Wits Mathematics Competition is hoping to draw participants from other African countries in the future.

Some African countries have also participated in non-African contests (other than the IMO) (Table 3):

2.6 PAMO & IMO

One of the aims of PAMO is to help prepare countries for participation in IMO, which is the largest, most prestigious, and longest-running science olympiad in the world. For example, it is South Africa's policy to send less experienced students to PAMO in the hope of developing them for IMO. The difficulty level at PAMO is generally lower than at IMO; the hardest questions at PAMO are usually at the level of the easiest questions at IMO. A student who gets a silver medal at PAMO would be expected to get an honourable mention or bronze medal at IMO.

There have been 31 African countries who have participated in PAMO and 20 African countries who have participated in the IMO (14 have participated in IMO since 2014, when South Africa hosted). However, some African countries have decided to participate in IMO with little or no participation in PAMO:

- IMO without PAMO: Angola, Madagascar
- IMO with little PAMO: Algeria, Egypt, Mauritania

Although we have not been able to directly verify with the organisers in these countries what their reasons are, we hypothesise that it may be due to the high cost of attending PAMO. Flights within the continent of Africa are usually in the same price range as flying from Africa to an external country. Therefore, if a country only has the budget to attend one competition, and has the choice between IMO and PAMO, they may choose to attend the more prestigious IMO. Furthermore, some countries might also view other non-African competitions as an alternative to PAMO; for instance, Angola participates in the Lusophone Olympiad for Portuguese-speaking countries.

In addition, PAMO organisation can be haphazard at times, with the competition being postponed, cancelled, or organised at the last moment. This can lead to issues with attracting funding or with obtaining visas in time. In comparison, the IMO is usually very well organised, with each host country decided at least four years in advance, and according to its website, IMO has run every year since 1959 apart from 1980.

3 Overview of the current landscape[16]

Based on attendance of PAMO and IMO, there is a small group of African countries that participates regularly and an even smaller group that performs reasonably well in these Olympiads. Performing well here means getting at least a bronze medal or an honourable mention in IMO or PAMO. Countries such as South Africa, Morocco, Tunisia, Nigeria, and Algeria have been consistent in obtaining medals and honourable mentions at the IMO; however, the other African countries have struggled to get any medals at all.

In July 2018 this struggle led to a meeting of the African team leaders and deputies at the IMO in Romania to discuss how these weaker countries could be assisted. The consensus was that the PAMO was not preparing these students enough for the IMO, and that more exposure to mathematical competitions was needed for younger students. The South African leader pointed out that their success lay in grassroots efforts and a multitude of internal competitions on various levels; however, many other African leaders replied that they do not have such programs and that it would be laborious and time-intensive to establish them. As a result, a new African competition for younger students was proposed (the African Junior Mathematical Olympiad, or AJMO) and an outline for its structure was drafted; however, nothing more came of these plans.

Generally, one cannot expect a student to come from the standard mathematics class and perform well in Olympiads, due to the emphasis on fully written proofs and the fact that the mathematical material (theorems, etc.) needed to solve most olympiad problems, although elementary, are not taught in school. Although PAMO and IMO are officially based on "high school math", most IMO participants who get a nonzero score will have been to various training sessions prior to attending IMO. For instance, South Africa's training and selection program is structured in such a way that each student will have been in the system for at least 18 months before joining the IMO or PAMO teams. Countries around the world have different training methods – camps, weekends and remote learning are all used. Usually these rely on many volunteers, most of whom have experience attending Olympiads as teenagers.

As can be seen from the annual booklets which are distributed by many non-African countries at the IMO detailing their internal competitions, there are many mathematics competitions at different levels that encourage and support students to engage in problem solving; this is rarely the case in African countries (a major exception is South Africa: (Laurie & Merry, 2001) (Merry, 2002) (van Zyl, 2003, 2004)). In addition, there are very few African countries that have math competitions at the primary school level, or lower secondary level; the students are therefore exposed quite late, when in secondary school. This means they are not well grounded and experienced in the culture, techniques, content, and methods of mathematics contests. The selection test for the national team can be the first contest a student sits in some cases.

The organisers of the Mathematical Kangaroo and the Wits Mathematics Competition are attempting to expand their competitions into more African countries. These are grassroots-level competitions which only require a teacher to sign up and administer the competition for their students and may fill the gap that the AJMO was intended to.

Some team leaders have built partnerships with countries that have more experience in olympiads. The partnerships have yielded improved performance at the IMO for Ghana and Uganda, who have a collaboration with the MIT-Africa

[16] Most of the material in this section is based on the authors' experiences and communication with the IMO team leadership in various African countries.

program; students from MIT have taught at training camps in February 2020 in both countries. Also, South Africa has had joint training camps with Austria and is currently collaborating with Estonia, one result of which is the annual South Africa-Estonia (SAFEST) Olympiad.

With increasing access to the internet some students and teachers can train independently through websites such as https://artofproblemsolving.com/. There are free resources available, though this is not sufficient.

4 Teachers and mathematical competitions

As many mathematics competitions rely on teachers at every stage (from organising student participation to motivating and training students), the attitudes of the teachers remain very important.

Through the authors' work in various countries in Africa, and through discussion with competition organisers in different places, we can see that in many cases, teachers are enthusiastic about running competitions for their students. This is especially true when the reputation of the school is at stake. In many countries, such as Rwanda, top performing schools will push their students to take part, and school websites will boast of past performance in competitions. Many teachers want to see their students do well, and they understand the benefits of taking part in competitions.

However, not every school or teacher is as dedicated or interested. When organising competitions, motivating teachers to assist can be a struggle. As secondary school teachers are expected to teach a lot of classes on a small salary across most African countries, expecting them to do extra work such as invigilation or marking can be unrealistic. Teachers are unlikely to put effort into supporting activities that are not curriculum based. When the communication of the importance and relevance of a competition is not clear, it is unlikely that teachers will be motivated to become involved.

We carried out a survey of teachers in different countries in Africa to gauge their attitude towards mathematics competitions. Although we spread the survey in various channels, most of the teacher responses were from South Africa (18) (the survey was sent to a mailing list of teachers who invigilate contests at their schools), Rwanda (27) (the survey was sent to teachers who took part in mathematical problem solving courses at the African Institute for Mathematical Sciences in Rwanda) and Kenya (6). Altogether we had 65 usable responses from 10 countries: Benin, Botswana, Cameroon, Ethiopia, Kenya, Morocco, Nigeria, Rwanda, South Africa, and Uganda.

This led to some biases in the data. For the teachers, most of those who filled in the survey are involved in running competitions, and so are members of the group of teachers who think competitions are worth running. Teachers who are not interested in running or supporting mathematics competitions were unlikely to be invited to fill in the survey, though we did ask teachers to share the survey with their colleagues.

Almost all teachers who responded had helped to run competitions for their students, in part because of the way the survey was sent out and the contacts available to the authors. Therefore, the following responses are biased towards teachers who put time and effort into running competitions; thus, they generally would agree that competitions are important.

We first asked teachers what the reasons were that prevented them from taking part in competitions. The biggest factor mentioned was that they were not invited to the competition or it not being at the appropriate level (12 mentions), followed by budget constraints (8 mentions), not having time to organise it (2), and internet connectivity issues (1).

Although most teachers responding had taken part in competitions, these responses can be taken as a small insight into the barriers facing other teachers across Africa. Some countries do not have well established mathematics competitions, as reported in Sect. 2. Other countries have competitions that only involve some schools, or some levels within the school system. In general, it seems that there are little to no opportunities for the average African school to take part in competitions, as even well-established competitions in countries like South Africa and Uganda are attended by less than 50% of the schools.

For many competitions, there is either an entrance fee (for example the Kenyan Mathematical Olympiad to which any school student can sign up for a fee of 300 Kenyan Shillings per student, just under 3 United States dollars), or students are expected to travel (at the schools' expense) to a test centre. For schools (or students) with small budgets, this cost can be large enough to prevent students from taking part.

Some competitions are run online and are free of charge. However, the school needs to have internet access, and the teacher needs to find time to administer and invigilate the exam. As indicated above, teachers find it difficult to do so, even if they want to. Although internet connectivity was mentioned by only 1 teacher as an issue, because the survey was carried out via the internet, we have self-selected teachers who can access it. Many rural schools across Africa do not have strong internet connections, and the cost of data bundles can restrict the teachers' ability to get online.

4.1 Discussion of survey answers

We set out to find out if the teachers thought that competitions were important, and how important they were to students. We also wanted to know how the competitions affected teachers. For each question, teachers were asked to rate, on a scale of 1 to 5, how much they agreed with the statements, with 1 denoting strong disagreement, 3 denoting neutrality and 5 denoting strong agreement. The total number of responses was 73.

Two main themes emerged out of the survey answers. These two themes are:

- Participating in competitions leads to more preparation
- Participating in competitions leads to greater enthusiasm

4.1.1 Participating in competitions leads to more preparation

We can see that participating in competitions leads to more preparation. When teachers were asked "My students learn things in competitions (or while preparing) that they would not have learnt otherwise" 37 strongly agreed with a mean of 4.10 and a median of 5. Another reason people run competitions is to encourage students to learn new mathematical concepts and expand their knowledge and it seems the teachers agree.

This was also strongly supported by the results of the question "I help my students to prepare for mathematics competitions – in addition to normal curriculum things" with 35 strongly agreeing, a mean of 4.09, and a median of 5. Despite the heavy workload that teachers often have, it seems that the teachers in this survey assisted their students in preparing. This varied across countries – Rwanda (4.59), Botswana (4) and South Africa (3.55) all agreed to different degrees.

This is not just true on the participants' side, but also for teachers based on the question "I learn new things to help my students to prepare for mathematics competitions" where 43 strongly agreed, the mean was 4.43, and the median was 5. Although competitions are usually designed to encourage students to learn more mathematics, we can see that competitions can also be a good way to improve teachers' knowledge of mathematics.

Furthermore, another two questions "Students work hard to prepare for the competitions" and "I work hard to help students prepare for the competitions" also supported this. Respectively 37 and 38 strongly agreed with this, the means were 4.2 and 4.26, and the medians were both 5. However, it is interesting to note that teachers seem to feel a responsibility to prepare the students for competitions.

4.1.2 Participating in competitions leads to greater enthusiasm

We can also see that participation in competitions leads to greater enthusiasm about mathematics. When teachers were asked "My students are more excited about mathematics for competitions than they are about curriculum mathematics", 25 strongly agreed with a mean of 3.76 and a median of 4. One aim of many competitions is to make mathematics more interesting and exciting to students. However, it seems that teachers only somewhat agree with that statement, with 19 teachers choosing "3 – neither agree nor disagree". Hence although the results are positive, they are weaker than the results about more preparation.

Similarly, we also see positive but weaker results with the question "My students seem more interested in mathematics when there is a competition" where 29 strongly agreed and there was a mean of 3.93 and a median of 4. Although the students may not be excited (as per the previous question), teachers tend to agree that the students are more interested in mathematics.

When asked "My students get turned away from mathematics because they do not perform well in competitions" only 8 strongly agreed, the median was 2, and the mean was 2.56 which means teachers generally disagreed with this statement (19 strongly disagreeing and 18 somewhat disagreeing). This indicates that participating in competitions leads to enthusiasm more than it leads to discouragement.

This is also not just applicable to students, but also to teachers, since when asked "I feel motivated when my students do well in competitions" 53 strongly agreed with a mean of 4.63 and a median of 5. However, the flip side of this is that teachers may feel unmotivated if their students do not do well in competitions.

4.2 Participating in competitions is important

The two themes (more preparation and greater enthusiasm) that emerged indicate that participation in competitions is viewed as important. This is furthermore supported by the question "I think it is important for students to take part in mathematics competitions" where 55 strongly agreed, the mean was 4.7, and the median 5. Teachers generally agreed with this somewhat leading statement; only two teachers (from Ethiopia and Rwanda) disagreed and selected "somewhat disagree". A caveat is that the teachers selected to fill in the survey would tend to be those who think that competitions were important, otherwise they would have been less likely to have received the request to fill out the survey.

Of particular importance is the question "I think that mathematics competitions are useful to all students, even if the student is not at the top of the class in mathematics" where 38 strongly agreed with a mean of 4.12 and a median of 5, which indicates that teachers view competitions not just for the most gifted. In some countries, teachers agreed more – for example, in Rwandan teachers the mean was 4.48, while in South African teachers the mean was 3.61. This may reflect the types of competitions offered; in Rwanda, the first rounds of some competitions are designed so that the

Table 4 ANOVA values highlighting the differences among Rwanda, South Africa, and Kenya

Question	Kruskal-Willis p value	ANOVA p value	Rwanda	South Africa	Kenya
I think it is important for students to take part in mathematics competitions	0.3892	0.477	4.815	0.468	4.5
It is important to me that my students do well in mathematics competitions	0.004	0.028	4.630	3.895	4.375
My students are more excited about mathematics for competitions than they are about curriculum mathematics	3.737×10^{-4}	1.97×10^{-4}	4.542	3.278	4.200
My students learn things in competitions (or while preparing) that they would not have learnt otherwise	0.84	0.605	3.963	4.316	4.125
My students seem more interested in mathematics when there is a competition	2.99×10^{-4}	7.09×10^{-5}	4.556	3.211	3.75
I think that mathematics competitions are useful to all students, even if the student is not at the top of the class in mathematics	0.014	0.0289	4.481	3.632	4.25
My students get turned away from mathematics because they do not perform well in competitions	0.038	0.0267	3.111	2.053	2.75
I help my students to prepare for mathematics competitions – in addition to normal curriculum things	3.27×10^{-3}	8.94×10^{-3}	4.593	3.555	4.000
I feel motivated when my students do well in competitions	0.144	0.214	4.741	4.368	4.5
Students work hard to prepare for the competitions	1.841×10^{-5}	1.1×10^{-6}	4.667	3.158	4.25
I work hard to help students prepare for the competitions	4.455×10^{-5}	9.15×10^{-6}	4.769	3.368	4.25
I learn new things to help my students to prepare for mathematics competitions	9.288×10^{-3}	0.018	4.692	3.947	4

average student will get around 50%, while a strong student will score around 80–90%. However, in many olympiad and other problem-solving competitions, it is more normal that the average student will get around 0–20%, while a strong student will get 30–50%. The teachers apparently see these latter competitions as less useful to the average student.

Lastly the question "It is important to me that my students do well in mathematics competitions" where 42 strongly agreed with a mean of 4.38 and median of 5 show that teachers care about the results, but interestingly, the teachers agreed less with this statement than the previous one. It seems like the results of the competition are of slightly less importance than participation in a competition. Eight teachers choose 3 or less, indicating that they did not agree with the statement. However, teachers who put down a 2 or 3 for the previous statement put a higher number for this statement – it seems like if teachers do not generally agree that competitions are important, they will be motivated by a wish for their students to do well.

4.3 Country effects

For each of the above questions we ran both an analysis of variance (ANOVA) test and the non-parametric Kruskal–Willis Test to see if the answer differed by country. Because some countries had only a few observations we restricted these tests to the three countries with the most observations: Rwanda (27), South Africa (19) and Kenya (8). The ANOVA test assumes normally distributed data which is not necessarily true here. Similarly, the Kruskal–Willis test is designed for distinct values (and a one to five scale contains many ties). Additionally, the sample sizes are smaller than we would desire so these results should be interpreted with some caution.

In the table below, we tabulate the Kruskal–Willis and ANOVA p values and means by country for each of the above questions. Questions in bold have low p values (< 0.05), and this can be interpreted as the countries being different in how they answered the question (Table 4).

We can see that the countries are quite different in their answers, with South Africa generally answering less positively. It would be interesting to explore further what influences the teachers' attitudes, and if there are ways for contest organisers to improve the teachers' views towards competitions.

From the survey, we can see that generally mathematics competitions are viewed in a positive light by teachers. The teachers think that students generally gain from the competition through being more interested in mathematics and learning new things. Teachers also put a lot of effort into preparing their students, going beyond what is required by the curriculum.

Table 5 Summary statistics for student questions

Question	Mean	Median	# strongly disagreeing	# disagreeing	# neutral	# agreeing	# strongly agreeing
Do they enjoy math competitions?	3.678	4	10	6	19	19	33
Do they learn more?	4.46	5	3	3	3	20	58
Do they become more motivated?	3.713	4	9	11	14	15	38

5 Students and mathematical competitions

A survey was sent out to African students, and 111 students replied: 105 from English-speaking countries and 6 from French-speaking countries. Most of the responses came from the African Institute for Mathematical Sciences' Alumni network. Thus, we have targeted those who have stayed in science/mathematics fields in university, indicating that they enjoyed mathematics and science in school, and probably enjoyed mathematics competitions.

Some results from the survey are the following, summarised in a table and with some additional comments following (Table 5).

5.1 Do they enjoy mathematics competitions?

A total of 87 former students were pooled and asked if they enjoyed olympiad mathematics more than class mathematics. A noticeable feature here is that this data comes primarily from the olympiad community and is therefore probably biased towards those who enjoyed olympiad mathematics more. A mitigating factor is that those who participate in olympiads are likely to be those who enjoyed class mathematics.

5.2 Do they learn more?

The same 87 were asked if they learned new things from competition mathematics. The overwhelming consensus is that these students felt that they did learn additional material from competition mathematics. Again, the sample is biased towards those who remained in the olympiad community. Perhaps those who felt that they were not learning a lot of new mathematics left after high school.

5.3 Do they become more motivated?

The same 87 were asked if they worked harder for mathematics competitions than for school mathematics. The results suggest that many were in fact motivated to do extra work.

Table 6 Correlations between enjoyment, learning, and motivation for secondary school students

	Enjoyment	Learning	Motivation
Enjoyment	1.000	0.388	0.392
Learning	0.388	1.000	0.335
Motivation	0.392	0.335	1.000

Table 7 Mean values for enjoyment, learning, and motivation for Kenya, Nigeria, Rwanda, and South Africa

Country	Sample Size	Enjoyment	Learning	Motivation
Kenya	17	3.529	4.294	3.470
Nigeria	10	2.500	4.500	4.300
Rwanda	17	3.882	4.412	4.24
South Africa	26	4.142	4.571	3.321

5.4 Correlations

There were four countries with reasonably sized populations of students in this group (Table 6). A table of the mean scores of Enjoyment, Learning, and Motivation are listed below. While they display some variation, some of this is due to the relatively small sample sizes; running ANOVA and Kruskal–Willis tests on all three variables of interest showed Enjoyment to be significantly correlated with country at the five percent level and Motivation to be significant at the 10 percent level (ANOVA placed Motivation as marginally significant at the five percent level while Kruskal–Willis placed Motivation as marginally insignificant at the five percent level). As in the previous section, assumption of normally distributed data is violated here, and these results should be interpreted with caution (Table 7).

5.5 For those who go to PAMO/IMO, what are the main benefits (of PAMO/IMO or of competitions in general)?

Our dataset contained 47 elite students who had competed at the international level, i.e., had participated in the IMO, PAMO or other international competitions. For purposes of

Table 8 Tallies of responses towards questions of enjoyment, learning, and motivation for competition mathematics, as well as a positive push towards STEM careers

	1 – strongly disagree	2 – somewhat disagree	3 – neutral	4 – somewhat agree	5 – strongly agree
Enjoyment	3	0	8	8	22
Learning	0	2	2	7	30
Motivation	0	2	7	12	20
STEM	2	1	4	14	19

Table 9 Mean values for the enjoyment, learning, motivation, and STEM questions for the IMO, PAMO, and 'other' segments

Averages by Group	IMO	PAMO	Other
Enjoyment	4.923	3.833	3.688
Learning	4.692	4.417	4.625
Motivation	4.615	4.167	3.938
STEM	4.308	4.083	4.133

Table 10 Tallies of numbers of camps attended by the students

Number of camps	1	2	3	More than 3
Number of students	7	11	4	16

this analysis, we have counted those who participated in the IMO and other competitions (possibly including PAMO) as IMO participants. Those who had participated in PAMO and not IMO, but possibly other international competitions were classified as PAMO competitors.

The data below shows how such participants reported benefits (Table 8):

In this table Enjoyment, Learning and Motivation are measured by the questions in the previous sections. STEM measures whether students felt that they would be turned towards a science, technology, engineering, or mathematics (STEM) career by mathematics competitions (Table 9).

Those who participated listed the chance to interact with other mathematically inclined students, problem solving skills, and preparation for undergraduate mathematics as benefits of competing in mathematics competitions.

5.6 For those who attended mathematics training camps, what are the benefits?

We had a total of 38 students who had attended camps. The number of camps these students attended is tabulated below (Table 10).

The campers' stated answers to which level of benefit they experienced are tabulated below (Table 11).

Interestingly while each benefit seemed to have a single student who did not feel that they did not receive said benefit these are not the same student. The student who did not enjoy the competitions claimed not to have been motivated to work harder for competitions but the low scores for Learning and STEM were put in by a second and third student.

Correlations between the benefits of enjoying competitions, learning from preparation, and being motivated to work for them were computed with whether the student reported having been inspired to pursue a STEM major at university and with how many camps were attended (we made the slightly unrealistic assumption that more than 3 camps was 4 to get numeric answers). Interestingly, enjoyment, motivation, and whether the student pursued a STEM major were strongly correlated, but all were almost entirely uncorrelated to learning.

Perhaps most surprisingly the number of camps attended was negatively correlated with learning! However, it was mildly correlated to enjoyment, motivation and whether the student ended up in a STEM field (Table 12).

5.7 Does participating in competitions lead to opportunities?

We had 171 respondents (both students and teachers) who have themselves participated in competitions (teachers with competing students are not counted). We asked them about various benefits. The first benefit we asked about was whether they were in contact with other olympiad people. A table of responses is below (Table 13).

We then asked students if camps and competitions had:

1. Made them more interested in STEM careers,

Table 11 Tallies of how many students reported each level of benefit for the enjoyment, learning, motivation, and STEM questions

Campers	1	2	3	4	5	blank
Enjoyment	0	2	4	8	21	3
Learning	1	0	0	8	26	3
Motivation	1	1	4	8	21	3
STEM	3	1	1	9	19	5

Table 12 Correlations between enjoyment, learning, motivation, likelihood to pursue a STEM career, and number of camps attended

	Enjoyment	Learning	Motivation	STEM	Camps
Enjoyment	1	− 0.023	0.633	0.222	0.259
Learning	− 0.023	1	0.004	0.082	− .169
Motivation	0.633	0.004	1	0.492	0.155
STEM	0.222	0.082	0.492	1	0.083
Camps	0.259	− 0.169	0.155	0.083	1

Table 13 Tallies of numbers of other Olympiad people with whom students were still in contact

Not in contact	With 1 person	With 2 people	With 3 or more people	No answer
36	8	8	34	85

2. Led to opportunities (e.g., scholarships) that would not have been possible otherwise, or
3. Helped them see that mathematics is broader than they thought from school mathematics.

The results are the following:

Students were also asked about other benefits (Table 14). The most cited ones were meeting like-minded people, learning new techniques, and prizes.

6 Conclusion

There are very few African countries with more than one mathematics competition in them, and many have none. This can be interpreted as a lack of mathematics competition culture in the African continent. There are various challenges faced by new and existing organisers of mathematics competitions, by trainers for these competitions, and by new entrants to these competitions, and thus there is an opportunity for innovation to find ways of running and training for these competitions that will work well in the African context. One possibility would be internationally organised competitions which are pitched at a lower difficulty level than the PAMO and IMO, are accessible to a wide range of ages, and are easy for teachers to administer, such as the growing Kangaroo and Wits Mathematics Competitions. There is also a serious need for trainers to be better equipped; perhaps an international African platform where those trainers in better performing countries can train those from other countries and share materials with them. A well-connected and widespread network among the African countries would also help organisers and trainers share methods with each other, possibly leading to more efficient use of time and resources and less duplication of effort, and thus lessening the burden on teachers who already have full time teaching jobs to attend to.

Most of the teachers who have organised for their students to take part in mathematics competitions report a positive effect on their students and are willing to put in the time to continue organising mathematics competitions for their students. However, there do seem to be some differences between countries on this front; future more extensive research may further elucidate this question. Most students reported that they enjoyed mathematics competitions and learnt more through taking part in them, and those who had graduated from secondary school reported that they felt more of a push towards STEM careers because of mathematics competitions; this highlights the importance of mathematics competitions in Africa in advancing Africa scientifically and technologically over time. It is thus our hope that mathematics competitions in Africa may grow in leaps and bounds in the years to come, and that innovative means of running these competitions are established to facilitate this growth.

Appendix: Survey Questionnaire

A list of questions in the survey which was sent out is given below:

Section 1 (for everyone):

1. Which of the following categories applies best to you?

   a. School teacher
   b. School student
   c. University lecturer
   d. University student
   e. AIMS alumni

Table 14 Tallies of responses to questions about interest in STEM careers, increases in opportunities, and exposure to extra-curricular mathematics

	1	2	3	4	5	No reply
STEM	2	4	19	12	45	89
Opportunities	15	9	19	16	22	90
Broadness	2	3	15	18	44	89

f. Other

2. Have you (or your students) taken part in a mathematics competition?
3. My gender is…

a. Male
b. Female
c. Other/prefer not to say

4. Which African country are you from?

Section 2 (for students):

5. Did you do any mathematics competitions while you were (are) in High School / Secondary School?

a. Yes
b. No – there are none that I know of
c. No – there are competitions in my country, but I did not take part

6. If yes, were the competition(s) based on the school curriculum or were they in the olympiad/problem solving style?

a. Curriculum based
b. Problem solving

7. Was the competition used for selecting a national team for the Pan African Mathematics Olympiad, International Mathematical Olympiad, or other international competition?

a. Yes
b. No
c. I don't know

8. Name of competition(s)
9. What percentage of students at your school took part in the competition(s)?
10. Did or do you receive any extra training related to problem solving maths? (Select all that are applicable)

a. Yes – in my school we had a maths club/team
b. Yes – I attended at least one maths training camp/event
c. Yes – I was sent material (assignments/notes) that I worked on at home
d. No

11. If your school did not take part in competitions, what are some of the barriers to participation?

a. Were not invited to participate
b. Did not know how to join
c. Budget reasons
d. Didn't have students at appropriate level for available competition(s)
e. No competitions in my country

12. In which year did you/will you graduate high school/secondary school?

Section 3 (for students) answered on a scale from Strongly Disagree to Strongly Agree:

13. I enjoyed doing maths competitions more than I enjoyed maths class
14. I learned new things while preparing for competitions
15. Not doing well in a maths competitions led to me liking mathematics less
16. My teacher helped me to prepare for the maths competition
17. I worked harder for the maths competitions than I did for normal maths class
18. Many people in my class felt disheartened after the maths competition as they did not perform well
19. Maths competitions helped me to realise I want to do a STEM related subject at university

Section 4 (for past IMO/PAMO participants and people who have attended training for maths competitions):

20. Have you represented your country at international maths competitions? Please select all that apply.

a. IMO
b. PAMO
c. Other

21. How many maths camps have you attended (of at least 3 days)?
22. Currently I am….

a. Math student at university
b. Math lecturer/researcher
c. Other STEM field student at university
d. Working in industry
e. Unemployed

23. Have you since helped other students to become involved in maths competitions?

a. I have helped train other students
b. I have helped to run competitions
c. No

24. Are you in regular contact with participants of the competition you attended?

a. No

b. Yes – with 1 person
c. Yes – with 2 people
d. Yes – with 3 people

The rest of the questions in this section were answered on a scale of agreement as before:

25. Attending camps/competitions made me more interested in pursuing STEM (science, technology, engineering, and Mathematics)
26. Attending camps/competitions led to opportunities for me that would not have been possible otherwise (scholarships/admissions to good universities)
27. Attending camps/competitions helped me see mathematics as a broader and more interesting subject than I had thought in school
28. Are there other benefits you got from participation in training or attendance at competitions?
Section 5 (for teachers):
29. What is the highest level of school students you teach?

a. Primary
b. Lower secondary/O-level
c. Upper secondary/A-level

30. Have students in your school taken part in a mathematics competition in the last 2 years?
31. Has your school taken part in a mathematics competition that is not curriculum based (Olympiad/problem solving style) in the last 2 years?
32. Name of competition(s)
33. What percentage of students at your school took part?
34. If your school has not taken part in mathematics competitions, what are some of the barriers to participation?

a. We were not invited to participate
b. Did not know how to join
c. Budget reasons
d. Didn't have students at appropriate level for available competition(s)
e. No competitions in my country
f. Don't have time to organise it

Section 6 (for teachers) answered on a scale from Strongly Disagree to Strongly Agree:

35. I think it is important for students to take part in mathematics competitions
36. It is important to me that my students do well in mathematics competitions
37. My students are more excited about mathematics for competitions than they are about curriculum mathematics
38. My students learn things in competitions (or while preparing) that they would not have learnt otherwise
39. My students seem more interested in mathematics when there is a competition
40. I think that maths competitions are useful to all students, even if the student is not at the top of the class in mathematics
41. My students get turned away from maths because they do not perform well in competitions
42. I help my students to prepare for mathematics competitions—in addition to normal curriculum things.
43. I feel motivated when my students do well in competitions
44. Students work hard to prepare for the competitions
45. I work hard to help students prepare for the competitions
46. I learn new things to help my students to prepare for mathematics competitions.

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