

Modern Mathematics Communications — An Asian Focus

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Abstract. The article introduces IMAGINARY, a project that started out as a single mathematics exhibition and has since grown into a full non-profit organisation over the last ten years. It tries to address questions such as: ‘How can we best communicate mathematics?’, with interactive and stimulating exhibitions, online resources, and exploring any imaginable way to communicate mathematical concepts. One of its defining features is that it also addresses current mathematics research topics. Here we will give an overview of past events, and exhibitions organised by IMAGINARY with a focus on Asia, as well as to give a how to guide to how future mathematics related exhibitions and events can be organised and implemented.

1. Introduction

How do we best communicate mathematics to a broad audience? The last 20 years have seen many initiatives for communicating science and mathematics [1]. While initially the hurdle of ‘Why should we communicate mathematics?’, had to be overcome. It has since been clear that we should now focus on different ways mathematics communication can be achieved. The following article draws from ten years of experience in designing, organising and disseminating interactive mathematics exhibitions under the umbrella project called IMAGINARY. The article has taken inspiration from [2] and [3].

2. IMAGINARY — How It All Started

IMAGINARY started as a travelling exhibition for the German Year of Mathematics in 2008. It grew as part of the Mathematisches Forschungsinstitut Oberwolfach (MFO), initiated and pushed forward by the former MFO director Gert-Martin Greuel and Andreas Matt, the now managing director of the IMAGINARY non-profit organisation. The initial exhibition, IMAGINARY — Through the Eyes of Mathematics, contained a collection of state-of-the-art mathematical visualisations and interactive programs. The flagship of the exhibition was a program called SURFER, which interactively explores the relationship of polynomial equations and 3-dimensional shapes.

The 3-dimensional shapes represent the solution of these polynomial equations [4].

In 2013 at the UNESCO headquarters in Paris, France, the IMAGINARY online platform — imaginary.org — was launched, hosting a variety of online resources for mathematics communication, including two of the IMAGINARY exhibitions [5]. This is also the place to find all resources to stage your own exhibition as discussed in Sec. 5. Over the last ten years IMAGINARY exhibitions have been put together in collaboration with local partners in more than 160 cities, 55 countries and 28 languages. The Google Maps markers in Fig. 1 represent all places in the world where an IMAGINARY exhibition or related event has taken place. To date, there are more than ten permanent IMAGINARY museum installations, see for example the algebraic geometry exhibition based on SURFER at the Museum of Mathematics in New York City, USA, in the left panel of Fig. 2. At the newly opened Ramanujan Math Park in the Agastya Campus, India, there are several interactive touchscreen stations with a collection of small mathematical apps and games called Math to Touch — a collaboration of IMAGINARY with Jürgen Richter-Gebert [6]. One of them is shown in the right panel of Fig. 2. IMAGINARY also has a permanent exhibition at the Deutsches Museum in Munich, Germany, one of the world’s oldest and largest science and technology museums. The success of the project has then lead to the creation of the non-profit organisation in 2016, paving the way for the expansion of the ideas behind IMAGINARY further and being able to accommodate the growing team, aspiring to communicate mathematics. With its strong connection to and the roots at the MFO, the MFO is still a shareholder of the newly created non-profit organisation. The creation of the new organisation was possible with generous funds from the Leibnitz Association. While still part of the MFO, the project was funded amongst other by the Klaus Tschira Foundation.



Fig. 1. Map indicating all locations with past IMAGINARY related events in the world.



Fig. 2. Left: An algebraic geometry exhibit created in collaboration with IMAGINARY at the Museum of Mathematics in New York City, USA. Right: An interactive touchscreen station with a collection of 16 small mathematical apps and games at Ramanujan Math Park in the Agastya Campus, India.

3. IMAGINARY — An Asian Perspective

Since so many IMAGINARY activities have taken place over the years it is difficult to adequately talk about them, but it is worth mentioning a few of the projects that have taken place in Asia and are currently planned. The first IMAGINARY event in East Asia was held in 2012 in Suzhou, China, in collaboration with Xian Jiaotong Liverpool University (XJTLU). The exhibition included several algebraic 3-D sculptures, a large collection of geometric images with English and Chinese descriptions, as well as five digital interactive

stations. The exhibition was accompanied by animations, slide shows and a catalog with bilingual explanations. During the exhibition, evening events included the showing of various movies on mathematics. Four years later, a new and even bigger IMAGINARY exhibition was on display at XJTLU as part of the 10th anniversary celebration of the university, see Fig. 3. Several satellite events took place, such as hands-on workshops on polyhedra and the SURFER software as well as general presentations and introductions to the work of IMAGINARY, which were held at different schools affiliated with XJTLU, see Fig. 4.



Fig. 3. IMAGINARY exhibition at XJTLU in Suzhou, China.



Fig. 4. IMAGINARY workshop in Suzhou, China.

In November 2013, a Mathematics of Planet Earth exhibition was shown at the Visvesvaraya Industrial and Technological Museum in Bangalore, India, see the left panel of Fig. 5. It was organised by the International Centre for Theoretical Sciences (ICTS) and Center for Applicable Mathematics (CAM) of Tata Institute of Fundamental Research (TIFR). The exhibition was based on the four major themes: Waves, Networks, Optimisation, and Structures. It featured more than 30 different exhibits, and it offered various outreach activities for school students and teachers such as open quiz sessions or hands-on astronomy based activities.

In the same year, IMAGINARY visited Vietnam: On the occasion of the International Con-

ference on Mathematical Research, Education and Applications (ICMREA — UEL 2013) held by University of Economics and Law, in Ho Chi Minh City, the IMAGINARY exhibition made its debut in Vietnam. The exhibition was accompanied by several lectures, and satellite events at the University in Quy Nhon City as well as at the Vietnam Institute for Advanced Study in Mathematics in Hanoi, see the right panel of Fig. 5.

In collaboration with the South Korean National Institute for Mathematical Sciences (NIMS), IMAGINARY presented the so far biggest exhibition at the International Congress of Mathematicians (ICM) 2014 in Seoul, South Korea. This special exhibition titled NIMS — IMAGINARY featured nine interactive touch screen stations, a



Fig. 5. Left: Mathematics of Planet Earth exhibition at Bangalore, India. Right: IMAGINARY exhibition at the Vietnam Institute for Advanced Study in Mathematics in Hanoi.



Fig. 6. NIMS-IMAGINARY at the ICM in Seoul, South Korea.

mathematical image gallery and 3D sculptures. The exhibition was attached to the congress, however accessible to the general public as well. Trained guides of the NIMS team, as well as of the international IMAGINARY team jointly gave introductions to the mathematical background of each exhibit and guided more than 10,000 visitors through the exhibition, among them many local visitors and schools. Afterwards, all exhibits were permanently installed at the NIMS headquarters in Daejeon, South Korea. Admission is free and guided tours are offered, making it especially attractive for school classes.

In December 2015, the first IMAGINARY exhibition took place in Taiwan, see Fig. 7. It was organised in collaboration with the Mathematical Society of the Republic of China (TMS) and held at the National Science and Technology Museum in Kaohsiung. The exhibition presented a variety

of mathematical content from IMAGINARY, including interactive software, large format picture galleries, films and 3D sculptures. Moreover, local experts contributed their works combining mathematics and arts to the exhibition, such as beaded sculptures, paper artwork and fractal paintings of traditional Chinese landscapes. A part of the large space of the professional exhibition setup was reserved for weekly workshops by local experts offered to the general public, see examples in Fig. 8. Additionally, IMAGINARY conducted several mathematics workshops on the SURFER software at high schools and different universities around Taiwan.

In 2016, the successful exhibition travelled to other Taiwanese venues, such as the National Taiwan Science Education Center in Taipei and the National Chiayi University. A small-scaled version of the exhibition is still travelling through



Fig. 7. IMAGINARY exhibition at National Science and Technology Museum in Kaohsiung, Taiwan. Left: beaded sculpture by Bih-Yaw Jin. Right: SURFER software.



Fig. 8. Workshops accompanying the IMAGINARY exhibition at different venues in Taiwan. Left: polyhedra. middle: ZomeTool. Right: SURFER.

Taiwan, visiting local high schools in less urban areas, with the aim to promote the development of mathematics in various aspects, to raise the public awareness of the subject, and to connect the beauty of mathematics with daily lives and arts.

In 2017, several tie-dye workshops took place in Indonesia using images of algebraic surfaces created with the SURFER software and transferring them onto textiles like cotton fabric using traditional tie-dye techniques, see the left panel of Fig. 9. These workshops took place at the Faculty of Science and Mathematics at the University Kristen Satya Wacana as well as during a STEAM themed summer camp in Agrowisata Salatiga, where STEAM refers to Science, Technology, Engineering, Art, and Mathematics.

Another IMAGINARY initiative worth mentioning is the Science Spaces project — a collaboration with the German language program of the Goethe Institutes all over the world [7]. One of the first workshops of this project took place in December 2017 in Vietnam: teams of high school students from three schools in Ho Chi Minh City together with guides from IMAGINARY developed science exhibits, which are now travelling in

a public exhibition. Experiments and exhibits are related to the STEAM subjects. Modern aspects, such as the interplay with art, sustainability, and science communication were examined as well (see the right panel of Fig. 9).

IMAGINARY will continue and strengthen the collaboration with the Ramanujan Math Park in India, already mentioned in Sec. 2, which was inaugurated on December 22, 2017, at its 172-acre Creativity Campus situated in Kuppam. Having drawn inspiration from the extraordinary works of Indian Mathematician, Srinivasa Ramanujan, the park aims to provide a space to promote learning, exploration, and discovery of ideas that convey a sense of the ubiquity of Math. By giving hands-on learning experience of math concepts, it aims to increase enthusiasm as well as reduce and eliminate obstacles in learning math, especially among economically underprivileged children [8].

4. IMAGINARY — and the Rest of the World

IMAGINARY did not only travel to Asia, but its successful travelling exhibition lead to many fruitful collaborations around the world. An example



Fig. 9. Left: Tie dye Workshop in Indonesia. Right: Science Spaces Workshop in Vietnam.



Fig. 10. Left: Pi-day celebrations in Tanzania. Right: AIMS-IMAGINARY exhibition and workshop in South Africa.

of an early collaboration is with Russia, where during the German–Russian Year of Education, Science and Innovation in 2011–2012 an IMAGINARY exhibition was shown in ten different Russian cities. IMAGINARY is also particularly engaged in mathematics communication in Africa with its tight collaboration with the African Institute for Mathematical Sciences (AIMS), in order to popularise mathematics communication on the African continent. As a first event, a pop-up exhibition was shown for the Pi-day celebrations in Dar es Salaam, Tanzania, in March 2014. This was followed up with a co-organised mathematics communication workshop and exhibition in Cape Town, South Africa, see Fig. 10 [9]. Since then, events and exhibitions have been organised in Senegal, Cape Verde, Mozambique, Democratic Republic of Congo, Liberia, and Rwanda.

Whole units of local IMAGINARY teams were established in several countries, e.g. Uruguay, France, and Turkey in addition to the before

mentioned units in Asian countries. Besides organising exhibitions, IMAGINARY activities also include school workshops, conferences, teacher trainings, etc. The most complete idea of how diverse and well spread events and exhibitions is best illustrated by the world map (Fig. 1).

5. How to Stage your Own Exhibition

So what is so particular about IMAGINARY and its global success in acting as a hub to transfer mathematical knowledge to the general public? One can attribute three key features to the project, while may be not unique, are definitely defining.

- (1) The project tries to address current mathematical research as opposed to many other projects. Its close ties to the MFO and other research institutions facilitate this.
- (2) It is international and multilingual in terms of collaboration, but also within the team of contributors.



Fig. 11. Holo-Math presentation in France, Photo by Camille Cier.

- (3) The projects runs based on a free, open access, and open source policy.

A further aim and appeal of IMAGINARY is to be as timely as possible, providing resources for touch screens and tablets, a modern and sleek web interface and the constant strive to move with modern innovations. This mixes the frontiers of mathematics research with state-of-the-art math communication. At the moment, IMAGINARY is looking for additional Augmented, Virtual and Mixed Reality exhibits [10], and is also participating in the international Holo-Math project, which will produce immersive live experiences in mathematical sciences using the latest mixed reality technology. New forms of augmented visualisation and interaction are core features. The experiences are presented in science museums/centers and at special events. They are targeted at groups of 20 participants led by human guides and virtual avatars [11]. In different Holo-Math experiences, participants will be able to play, discover, experiment, and learn about science history and current research. The first pilot experience on the topic of Brownian Motion has already been presented in a special event on October 17, 2017,

at the Palais de la découverte in Paris, France, see Fig. 11.

Let us now look at how one can actually organise an exhibition from the available resources. There are three or four obvious questions that need addressing, when creating a mathematics exhibition:

- Where should the exhibition take place?
- What should be shown?
- What is the budget for putting on the exhibition?
- How long should the event/exhibition go on for?

Choosing the venue: The dates of when the event happens is often defined by the available venue and should be the first thing to be chosen. The choice of venue is important, as it may end up dictating a few things. How accessible is the venue? How big is the venue? These questions will eventually define the audience most likely to visit the exhibition. If a university venue in a room far away from general traffic is chosen, the exhibition will be visited by fewer people and less likely to be visited by random members of the general public than if it was installed outside



Fig. 12. Different venue options (right image: courtesy of Heidelberg Laureate Forum Foundation).

at a central square of a town. You should choose your venues that suit your desired target audience and can be anything from colleges, universities, art galleries, schools, public squares, train stations, shopping malls, or bank foyers, see different venue examples in Fig. 12. Ideally a co-sponsorship can be agreed upon by the venue in order for it to be available free of charge. As for the budget; \$2000 should be sufficient to get you started with an exhibition, but going all the way up to \$200,000 will obviously generate quite different results in terms of appeal and ease to draw in audiences. In the end expenses will depend on the use of paid staff, or volunteers, number of exhibits and type of exhibits. Trying to find a sponsor is worthwhile or using a host institution such as a university may partly cover required costs. Sponsors can be found in the private and public sectors, such as government sponsorship, e.g. the Ministry of Research and Education in Germany, or banks and high tech companies and philanthropic organisations.

Choosing the exhibits: Exhibits can be categorised into four different types:

- Computer program: An interactive software exhibit running on a computer or hand held device
- Hands-on: An interactive exhibit requiring physical manipulation
- Film: A short film in a documentary or artistic style on a given topic, projected onto a surface, shown on a TV or in a dedicated cinema room
- Gallery: A collection of images and sculptures on display to be viewed but not interacted with.

A combination of the four different types will ensure that a visitor will be fully emerged in the exhibition, as different stimuli will appeal

to different people. The online platform www.imaginary.org hosts more than 100 potential exhibits that can be used free of charge in your own exhibition, with particular focus on current research topics. You will need to pay respect to the individual licenses of the chosen exhibits, e.g. mention the author.

In the following we will look at SURFER [4], the initial flagship software, in a bit more detail. Surfer is a real-time ray tracer of algebraic surfaces. The program renders the solution of a polynomial equation in real time. The visitor can interactively change the polynomial equations and explore the available solutions. The resulting surface, which represents all x , y and z coordinates, that satisfy the polynomial to equal zero, can be rotated, zoomed in and out of, and its colour can be changed. This interaction fascinates and casually transmits geometric intuition and mathematical understanding. SURFER comes with a set of gallery images and their corresponding equations that are often a nice starting point. Furthermore, it has an extensive tutorial section explaining how the program works and how the shapes display relate to the equations. Lastly, it also contains a section of so called *world record surfaces*, which directly connects to ongoing research topics in the field of algebraic topology in mathematics. It is possible for visitors to take their own created surfaces home, if a printer is connected to the program [3]. Often times, it creates a nice synergy to accompany the interactive program with gallery style prints of surfaces or even 3D printed surfaces. In the past the software has been used to stage online image competition, disseminated by popular newspaper and journals [12].

A large selection of content is available for the different types of exhibits. There is one exhibit, that does not really fit well into any of the above categories. This is an interactive station, which

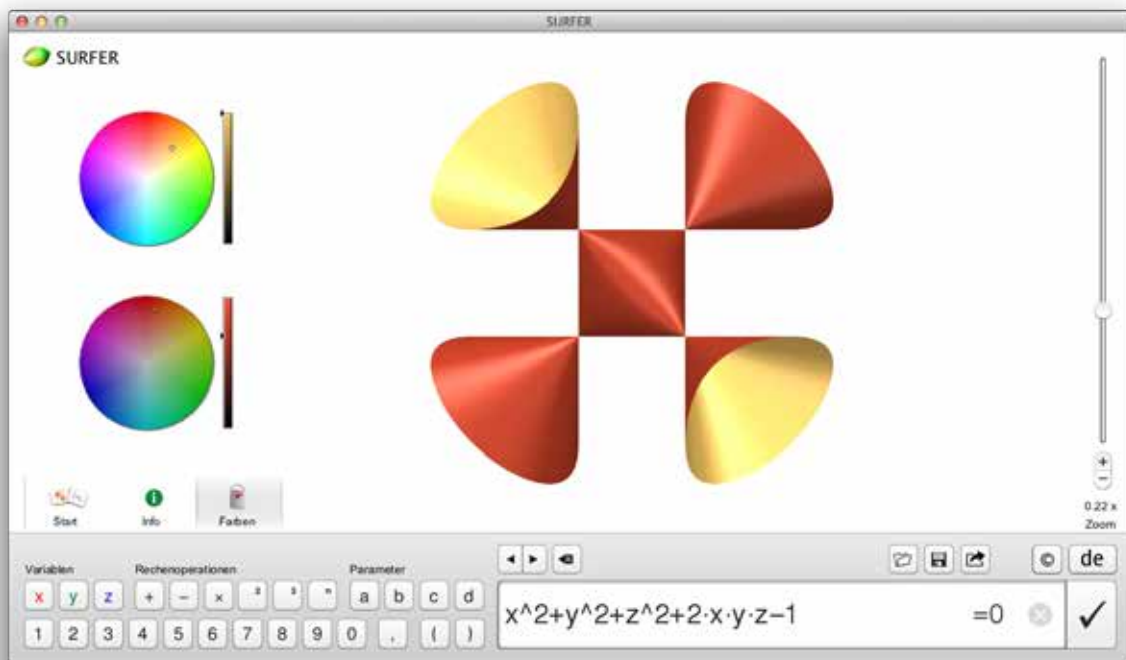


Fig. 13. The SURFER user interface.



Fig. 14. Submission examples from international SURFER competitions.

lets you choose among the library of “snapshots of modern mathematics” [13]. These snapshots are short articles written by participants of workshops organised at the MFO addressing current research in all fields of mathematics. The snapshots are edited and also available online [14]. The “snapshots” can be loaded onto a touchscreen station and become appealing and easily browseable. Again if attached to a printer, visitors can be encouraged to take printouts home or just receive them as an email.

Once the choice of venue, budget and exhibits is worked out, the actual realization of the exhibition is the next step. This requires to generate the exhibits (e.g. print galleries, acquire touch screens for media stations or produce a hands-on exhibit). Local venues such as universities may have some technology available that can be loaned otherwise it is important to budget for the acquisition of computers or touchscreen. Last but not least, it is important to sufficiently publicise your event.

A mixture of online (e.g. social media channels) and offline (posters, flyers) publicity is usually useful. Again the online platform can provide templates for flyers and posters facilitating this task. Often media work can be further assisted by using the public relations office of your institution or through the assistance of IMAGINARY’s media resources. The last thing that needs to be planned is the actual running of the exhibition, during the period it is meant to be on display. Is there going to be a public opening ceremony? Who is going to look after the venue, if no arrangements are made by the venue itself? Will you provide guides who are available to explain mathematical content in more detail? Are there going to be dedicated school visits with tours? Generally having explainers available on site has proven to enhance the exhibition experience significantly. Again there is material accessible online that will allow for the training of tutors and guides. If required, and the budget allows, IMAGINARY

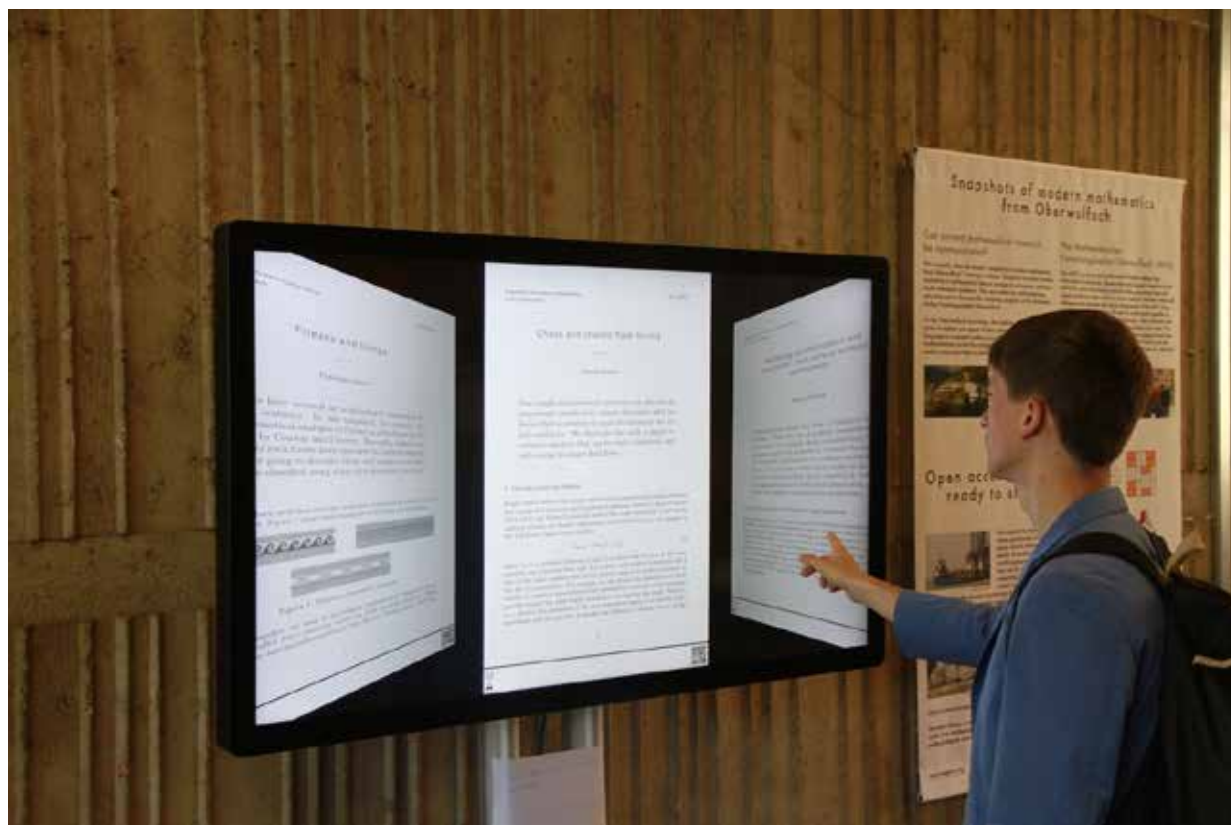


Fig. 15. Snapshots Slider — interactive station.

team members can help with the training and also support you in all other steps in the organisation and production of your exhibition. These services will need to be agreed on in a contract established in the organisational phase of the exhibition. If you want to organise an IMAGINARY exhibition and would like support, feel free to contact us. Once the exhibition period is over it may be nice to reuse some of the printed material in a more permanent fashion, for example decorating the corridors of your mathematics department. If you organise an exhibition, please announce your event to the online listing of all exhibitions at imaginary.org/events. There you can also find out about all current exhibitions and museum installations, including ones happening in the coming months in New Zealand, Uzbekistan, Germany, Rwanda — and may be a place near you!

6. How to create your own exhibit

Another unique aspect of IMAGINARY is the community approach. While it is possible to just use the provided content online, partners are usually encouraged to make contributions to the exhibition themselves. This contribution can be

simply a translation to a new language for one of the exhibits shown, or actually create novel exhibition content. Turning your own research into an exhibit, may not be as scary and daunting as it sounds. Over the years, a collection of ideas and practices on how to transfer mathematical knowledge into an exhibition has been established with IMAGINARY. Tools are available to create high resolution images, cameras for creating stop motion, introductions on how to generate 3D printable content. You can then choose to contribute your exhibit to the wider community, by making required information available on the online platform under an open license. However, this still means a required acknowledgement of the original author. One way we try and motivate the community to provide new exhibits is running competitions for new exhibits. IMAGINARY has done so in the past, which lead to the creation of the *Math of Planet Earth* exhibition, with a first round of competitions in 2013 and a second round in 2017 [15]. With the MathLapse competition in 2016 [16], IMAGINARY has launched a new educational and artistic format for short films and animations called *MathLapse* to highlight the link between mathematics and real-world phenomena.



Fig. 16. Impression of the exhibition “The Taste of Mathematics”, courtesy of Pedro Reyes Dueñas.



Fig. 17. Conveyor belt design at the Mathematikon shopping center in Heidelberg, Germany.

The name MathLapse is inspired by the timelapse-technique in physics: By re-scaling time, phenomena are visualised which we cannot observe directly. Watch out for future competitions, where your exhibit idea may even result in a cash prize.

Also not all ideas have to be strictly just communicating mathematical content. IMAGINARY is trying to bridge between math and arts as well as communicate mathematics, so even if your idea seems outlandish we would love to hear about it. For example, in 2012 surfaces that could easily be generated with SURFER were transformed into an exhibition called “The Taste of Mathematics”, see Fig. 16. IMAGINARY also permanently integrated mathematical content into a shopping center in

Heidelberg, Germany, called *The Mathematikon*, which opened in 2016. Main features are a mathematical image gallery, conveyor belt designs (see Fig. 17), a multi touchscreen station (see the middle panel of Fig. 12), riddles in the restroom, and at the bakery, classic quotes, as well as a temporary shop window display [17].

Inspired by the IMAGINARY open air exhibition (see the left panel of Fig. 12) in Ljubljana, Slovenia, organised by the MATHEMA institution for popularisation of mathematics in 2015, the renown local design company Draž produced mathematical knitwear for their Fall Winter 2016/17 collection. Draž processed the proposed visualisations of algebraic surfaces, adapted and



Fig. 18. Lady's coat, part of the Draž collection.

applied them to knitted textures. The result is a colourful collection with strong graphical elements and uneven silhouettes which follow individual knitted textures, see Fig. 18.

At the moment, IMAGINARY is looking for new exhibits for our upcoming exhibition on mathematics and music, explaining, demonstrating and displaying the fascinating relation between the two fields. We will connect music with modern mathematics and its applications, with artificial intelligence, big data, and neuroscience. Installations, interactive exhibits, and physical experiences will demonstrate the inseparable interlocking of both subjects. The exhibition is presented by the Heidelberg Laureate Forum Foundation and will open in spring 2019 in Heidelberg, Germany, at the Mathematics and Informatics Station called MAINS.

7. Conclusions

We gave an comprehensive overview of what IMAGINARY is and outlined steps that allow you to organise your own IMAGINARY exhibition or event. However, there are different ways to get involved with the IMAGINARY community. The IMAGINARY Conference on Open and Collaborative Communication of Mathematical Research is an interdisciplinary gathering of mathematicians,

communicators, and interested professionals who wish to discuss and work together on current issues of communication and knowledge transfer in mathematics. It took place in Berlin, Germany, in 2016 and is planned to be a biannual event, with the next IMAGINARY conference taking place in December 2018 in Montevideo, Uruguay. In contrast to a classical conference, we use a participative and collaborative approach in order to advance new ideas, bring forward concrete results and help shape the future of mathematics communication. The program consists of talks by community members as well as workshops, which are run in parallel. Participants work in small groups of up to 15 on specific projects, which can be achieved in the given time frame of three afternoons. Results are shown in a public presentation at the end of the conference and offered under an open license afterwards. These IMAGINARY conferences unite teams from all over the world and are a unique opportunity. You can sign up for the conference newsletter and find more detailed information on the upcoming conference in Uruguay on the conference website [18].

If you want to be informed about current mathematics exhibitions or trends in mathematics communication, please join the Mathematics Communication Network [19]. You can subscribe

to its newsletter and participate in joint projects and conferences. There are many extraordinary projects around the world that bring the beauty of mathematics closer to the general public, and each one of these has very valuable experiences worthwhile to be shared. We would be happy to work on joint ideas and to find out more about your experiences in mathematics communication.

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Co-founder and currently director of IMAGINARY, Andreas Daniel Matt worked as mathematics communicator at the Mathematisches Forschungsinstitut Oberwolfach from 2007 until 2016. He studied mathematics and computer science and did his PhD in mathematics in machine learning at the University of Innsbruck and the University of Buenos Aires. He curated the MiMa, a museum for minerals and mathematics in Oberwolfach, and is a member of the Raising Public Awareness Committee of the European Mathematical Society. He has received several prizes for his outreach activities, including the Media Prize of the German Mathematical Society in 2013 (together with Gert-Martin Greuel) for the IMAGINARY project.



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Antonia Mey works as a freelancer maths communicator and project manager for the non-profit organisation IMAGINARY. She obtained a PhD in Physics at the University of Nottingham in 2013 followed by a research postdoc at the Freie Universität in Berlin in the Department of Mathematics and Computer science, where she discovered her interest in professional Mathematics communication and public engagement and joined the IMAGINARY project in 2014. Since then she has helped with the organisation as well as managed various IMAGINARY exhibitions and other activities predominantly on the African continent. She is also an active researcher at the University in Edinburgh in the field of computer aided drug design.



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Chief Creative Officer at IMAGINARY, an international non-profit organisation for open communication of modern mathematics with its base in Berlin. She studied mathematics at Technische Universität Berlin, and did her masters in 2009. In addition, she is a certified film editor and combines both fields by creating several award-winning animations and visualisations. Since 2017, she is the chair of the Bridges short film festival. At IMAGINARY, she curates and organises exhibitions, is responsible for content development and communications, stages competitions, leads workshops and teacher trainings as well as other mathematics outreach events.