The Mathematikum in Giessen

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This short article is about our Giessener Mathematikum, a hands-on minds-on science centre which is unique in the world as an institution solely directed to reaching out to the general public in order to show that mathematics is an interesting and enjoyable subject for everybody. Given many unjustified prejudices against this subject from lay people, it was a challenge to create a large science centre that is attractive to everybody and aims to convince that the beauty, depth and usefulness of mathematics is comprehensible to all, independent of a particular education and particular scientific inclination. We believe we have succeeded, and my purpose is to outline the history and present operation of the Mathematikum, and its various ways of meeting the mentioned challenge.

The history dates back almost 30 years. It is all due to a professor who is well known in Germany for his expertise in mathematical outreach. In 1993, Professor Albrecht Beutelspacher of the Justus-Liebig University at Giessen in Germany asked students in a teachers' training exercise to build geometric models for school students with a careful explanation of their basis in mathematics. The enthusiastic students provided results that were so remarkable that they were exhibited to members of the university and the general public, only to be followed by the first exhibition outside Giessen, namely in Nuremberg.

An enlarged exhibition of models (we call them 'experiments' now) that was created specifically for the public, and no longer exercises for students in the university, followed in 1996. This was a springboard for an even larger presentation of experiments at the International Congress of Mathematicians at Berlin in 1998, and it attracted visitors to the tune of 10000.

A last test to see whether Beutelspacher's ideas and the ready-made experiments were suitable for a non-profit commercial set-up was carried out in Giessen in 2001, and after its tremendous success, one had to look whether a building and funding would be available for creating a real museum (nowadays a 'science centre') that offered attractive, enjoyable and

educational mathematical experiments to show the public how interesting, useful and entertaining mathematics can be. The main point was to prove that in spite of its reputation as a dry subject, mathematics can be interesting and fun, as reflected by our present motto: "Mathe macht glücklich!" (Mathematics makes you happy).

Many people are sceptical about mathematics being a pleasurable subject but after spending time, often many hours, in the Mathematikum, they do become convince that mathematics *does* make them happy. I personally carry out a simple test by walking out and about with my 'Mathe macht glücklich!' T-shirt and seeing whether anybody confronts me, perhaps with a negative view, having, say, just failed a mathematics test. This never happens. Instead, sometimes a first-time visitor tells me that he finds the slogan interesting and asks me what I mean by it.

Then, in 2002, faced with having to find a suitable building, we were lucky. The customs building close to the railway station (this proximity is definitely a plus for such a museum) was no longer needed by the federal government (in the middle of the European Union) and was available for us. A substantial renovation was necessary, first of all because of the age of the listed building (which increased cost) and secondly, because large, open spaces were needed instead of many small offices. (Actually there are two houses, linked by a glass construction clearly visible in the full front picture which is the entry area and contains tills etc.) A generous grant from the EU helped us with the renovations. An official visitor from the EU administration came along and met with me much later in order to see what we had done with the money; he saw the incredible crowds of people in the museum and was *most* satisfied!

With an enormous and successful effort by Beutelspacher and our staff, the project worked out well, and President Rau of the Federal Republic opened the Mathematikum in November 2002 as the first science centre of mathematics for the general public. Initially only two floors of the building were used, to see whether the concept worked out. Then, after the exhibitions were really flooded with visitors, the museum was expanded, covering four floors now and including a Mini-Mathematikum for the children of kindergarten and prep-school age. The Mini-Mathematikum was added using an elaborate construction underneath the roof and is self-dependent (with service rooms etc) so that people can have a good view of the children and see they are safe. During mornings from Monday to Friday when school groups are there, the Mini-Mathematikum is not open for the other visitors.

Initially, on the first two floors of the building, a minimum of one experiment was added each month. Naturally we needed to see first whether this approach caught on. And it did in an overwhelming way. Now, about 1200 square metres contain about 200 experiments which are visited by about 120,000 to 150,000 visitors each year. This, given the entrance fees averaging €7, avails the Mathematikum of a balanced budget with little additional support needed – but some extra money is welcome of course.

The Mathematikum is a tax-exempt non-profit society run by a Board of four (one being the author of the present paper) chaired by Albrecht Beutelspacher. We know it began in 2002. Some extra income results from the travelling exhibition and sale of experiments (see below). And there is sponsorship where, for instance, a construction company would pay for five years for an experiment where geometric objects are being *built*, and of course, its name would be mentioned in a sign close to the exhibit.

The staff is formed by some permanent employees, such as carpenters for an on-site workshop where most of the experiments are made; many of them have a wooden basis. The carpenters who are outstanding in their abilities to help with the creative process and the actual manufacturing of the exhibits. Of course there is administration, including finance, organising the shop and our travelling exhibitions, public relations, technical staff. A large number of staff are recruited, often from part-time students. They look after the day-to-day maintenance of experiments (cleaning exhibits, especially mirrors, refilling soap for our soap bubbles, undoing experiments and puzzles which have been solved by visitors and of course left like that). Moreover, they help with experiments but never explain in too much detail. The visitors need to and like to find out themselves–, they provide guided tours (again without details; this is not a 'static' arts museum!) raising interest and giving general ideas of concepts.

The idea is that visitors should find solutions and understand concepts behind mathematical problems that are entirely professional, never trivial, but presented in a way that is attractive to lay people. This is not easy! But the visitor should not necessarily see that behind the experiments there is an enormous amount of thought he or she should enjoy the result and learn from its presentation. The solid mathematical foundation behind the experiments ranges from Pythagoras' Theorem, via facts about π, cubic sections, combinatorics, music, cryptography (we have a working copy of the German Enigma machine), exponential functions (the famous chessboard with rice the amount of which is doubled from square to square), Penrose tilings, minimal surfaces (soap), binary numbers, Galton boards, the travelling salesman problem—visit and find the optimal route for seeing all capitals of German states beginning from Giessen of course, even to unsolved problems like the Goldbach conjecture. There are certainly surprises to be had but no unfair tricks or games; every exhibit has a mathematical foundation which professional mathematicians would agree to. Nonetheless the 'fun factor' is perfectly taken care of: imagine the number of visitors who have their photograph taken when they stand inside the big soap bubble!

We use our financial and organisational freedom that comes from the balanced budget and from our status as a non-profit independent organisation offering to visitors enjoyment and learning without the least pressure. There are no pre-stated goals or must-dos or must-haves, there are no forms to fill in or evaluations, let alone examinations of any kind, when leaving, no staff who ask particular questions. The organisational freedom

comes from the fact that the Mathematikum is *not* a part of the University, neither does it belong to city or state. Beutelspacher has now retired from the university to concentrate on directing Mathematikum. Three professors at the university (two who do research and one who teaches) also serve without pay (but are permitted by the University to participate like that, the Mathematikum being of course a big attraction to people of, as it were, both town and gown). The Mathematikum is, incidentally, next to the Liebig Museum that contains laboratories and a lecture hall of the famous chemist who is also well-known in Britain, but that has an entirely different concept; it is more a classical museum.

About 40% of the visitors are school groups who come Monday to Friday, and we offer training for the mathematics teachers too. In fact, many more activities are carried out at the Mathematikum such as talks, some scientific and linked to the local mathematics institute, education, special events for senior citizens, special days for the π-day, 14th March. Rooms can be rented for commercial events during the evenings, conference meetings or dinners, which often go along with tours and experiments of the Mathematikum. Further events include talks about particular subjects, sometimes scientific, sometimes for smaller children, and the 'red sofa', where Beutelspacher interviews somebody who has close connections with mathematics via the Mathematical Olympiad for example, or is some well-known scientist. All these events are public (usually for a small entrance fee) and very well attended indeed.

As well as the four floors of experiments which are loosely organised by subject (all open, no doors in between) there are facilities like a shop for books, puzzles and souvenirs—do not miss getting a 'Mathe macht glücklich' T-shirt—and a cafeteria. The subjects include circles and conic sections, perspective, exponentials, minimal surfaces, tilings, cryptography, music, probability, binary numbers, geometric theorems and proofs, statistics, optimisation, puzzles (e.g. sudoku), functions, notions of infinity, symmetries (mirrors are used to a large extent), distances (geodesics), music, combinatorics, chaos *vs*. mathematical stability, primes and their distribution. There are also tables with items for Lego-like constructions for example.

Many experiments throw light on mathematical concepts from various points of view, which helps enormously in understanding them. Here are a couple of examples. Conic sections are presented by approximations to π by counting steps on the floor around and across a marked circle (giving the famous approximation 22/7), ellipses are drawn using the gardener's method, and circles are covered cake-like with pieces which then can be taken out, trying (and failing, of course) to measure the area by a rectangle, there is a big cone filled with blue liquid one can turn to observe the horizontal area varying to form straight lines, parabola, hyperbola, circle and ellipse. And Pythagoras' Theorem is presented by its geometric proof (drawn on the wall), by dissecting the large square area and reassembling the pieces into the sum of the two smaller areas, also by putting the two areas a^2 and b^2

together on a scale and weighing it against the large square. One notices that these areas need not be represented by squares: rabbits or stars will do nicely if the bases (i.e. the bellies on which they sit) of the rabbits have the same length as a, b and c, respectively, and their areas are proportional. At the entrance and in front of the building are some examples and teasers. The facilities are on the left, and the exhibitions begin on the visitors' right-hand side. The modest cafeteria offers coffee, tea, cake, ice creams, sweets and sandwiches and we are not opposed to visitors, especially families and groups, bringing their own food. We have plenty of space for groups and facilities like storage boxes for large number of bags and rucksacks. The furniture for the cafeteria, entrance hall and these storage facilities are made in the same workshops and reminds one of the material of the experiments, which gives a uniform appearance to the whole museum.

FIGURE 1: Paraboloid with blue liquid

There is a court outside with a terrace where the visitors can enjoy themselves in the sunshine. Many visitors come by train because it takes only a one minute walk from the station (I mentioned that the proximity of the station is a plus, and we have an advertisement at the station), but there is enough space for buses outside. Visitors come from the whole of Europe. So the brief explanations usually on the wall close to the experiments are both in German and in English. These normally include naming the experiment and perhaps a mention of the name of the mathematician linked to it. Not only mathematicians feature here: Albrecht Dürer (projection), Escher (needs no explanation), Mozart (he created a piece of music whose parts can be permuted and all permutations give a perfectly sounding new piece) and unsurprisingly Leonardo da Vinci feature as well.

Many experiments are set up in this court and outside the building too, as an attraction and entertainment for people simply passing by more often than not they are lured into the Mathematikum by that. Outside there are also sculptures related to mathematics.

FIGURE 2: Penrose puzzle

A significant extra income is earned from the travelling exhibitions (we have five copies) that contain a subset of about two dozen experiments that are mostly smaller copies of the fixed experiments in the building. They are rented from all over the world, and all sorts of institutions including schools, universities and commercial enterprises use them typically for a fortnight (longer if they go to far away places even beyond the Continent) for a very reasonable price. Often these institutions admit visitors for a small fee from the general public so in the end the net cost tends to be minimal. A typical example would be a school that rents an exhibition for their pupils during the morning and admits the public, for a euro or two in the afternoon. A

couple of staff from the Mathematikum travel to set up the mathematical experiments and to collect them at the end.

We also sell experiments to outside institutions and more than once these were the basis for a new mathematics museum or part of a museum. When selling, we only allow new organisations to use our experiments if they are far enough (200 km) away because we do not wish unhealthy (i.e. geographically too close) competition, and of course the name 'Mathematikum' is copyrighted.

Concerning fabricating of experiments and their maintenance, all of our experiments work and are intact full time! If there are technical glitches they are fixed immediately by the staff and workshop on-site. All of them are large and very robust, and we see from the total absence of wilful damage and theft that people are seriously enjoying themselves and treat the objects with respect. This does not mean that they are not using them to their full extent, and we create experiments that are solid and high-quality. The attention to detail we give to the creation of an interesting and substantial experiment means that the results we achieve are considerable.

There are of course occasionally experiments that visitors find less attractive; this is perfectly normal. If we observe this, we remove them after some time, but this is rare. Old experiments or those of temporary exhibitions are stored in a warehouse elsewhere in Giessen.

FIGURE 3: The big soap surface

There are special exhibitions typically twice a year; the Mathematikum advertises those of course. They add attraction to the permanent exhibitions.

The centre is open every day of the week (unlike museums that are typically closed one day per week, often Monday) almost throughout the year (Christmas and New Year excepted), and there is a week for refurbishing (painting walls and so on) every year, typically in January when visitor numbers would be low anyway. A major refurbishment is undertaken every five years.

The underlying idea being 'hands-on minds-on' and indeed 'hearts-on' follows the well-established concept that learning by doing manually is often the best way of understanding science. We have hardly any computers and almost every experiment is hand made. Many of them are colourful but we pay attention to focussing the central idea on clearly identifiable objects with wooden tables and so on in the background. For the same reason, walls are almost everywhere white with sometimes drafts of concepts ('proof' of Pythagoras' Theorem, expansion of π, some history, . . .) on the walls. For the Mini-Mathematikum there are suitable chairs and carpeting for small visitors to crawl on. There are some lamps and light effects for showing perspectives for example, but no flickering or changing colours. There is plenty of space between the tables with experiments so that people feel at ease and their family and friends can watch while somebody does an experiment.

The whole atmosphere is relaxed while keenly attentive, but there is—there ought to be—call it 'positive noise' (no shouting, let alone yelling) and very audible excitement from our visitors when they communicate and have found something out, suddenly understand, suddenly solve the riddle, the famous 'Aha!'-effect. They leave excited, convinced that mathematics is interesting and useful, not at all boring, and they have learnt a lot, but in different ways from in schools.

I would like to point out that this is not a competition between us and the schools since this is not an academic institution as such. The schools' and the Mathematikum's ways of seeing, understanding and learning are simply different, they are not better or worse. And of course, the nature of reactions of visitors and students at schools are very different.

We get positive feedback, and criticism too, naturally, by letters and suggestions. We notice if and when people are coming again and again though we keep no statistics, other than the sheer count of visitors. Often I notice that a group to whom I give a brief introduction, who arrive wishing to spend an hour or so ends up staying the whole day. We wish the visitors to be happy and appreciative of mathematics when they leave, so that they come again, tell their friends and family about it, and perhaps decide to do something later on related to mathematics, sometimes even professionally.

There is a comprehensive online presentation of the Mathematikum [1]. We have press officers, and journals of all kinds and TV stations send teams and photographers. The photographs of experiments are from the public

relations and photography staff of the centre. Those included in this Article are from the Mathematikum website.

The success of the centre is underlined by the sheer number of international invitations Beutelspacher and I receive to speak about the ideas of the Mathematikum and to write about it, and for the same reason of course the *Mathematical Gazette* has asked me for this contribution.

Many (probably all) readers of the *Mathematical Gazette* need not of course be told that mathematics is an extremely important subject and that it is interesting and fun, but the way we offer mathematics to the public, taking a totally different approach, will be, I believe, interesting for you too. So I invite you to come to Giessen, see the Mathematikum and join us in our motto '*Mathe macht glücklich!*' .

Reference

1.   www.mathematikum.de

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The answers to the *Nemo* page from November 2022 on pulleys were:

1.	RD Blackmore	Lorna Doone	Chapter 43	Mr Huckaback's Secret
2.	Walter Scott	The Talisman	Chapter 5	
3.	Jonathan Swift	Ode to Sir William Temple	Verse 7	
4.	Henry James	The Aspern Papers	Chapter II	
5.	Charles Dickens	A Tale of Two Cities	Chapter 5	The Wine Shop
6.	GK Chesterton	Alarms and Discursions	Chapter 28	The Wheel

Congratulations to Martin Lukarevski and Henry Ricardo on tracking all of these down. The topic this month (in more ways than one) is iteration – the repeated application of a process. Quotations are to be identified by reference to author and work. Solutions are invited to the Editor by 23rd May 2023.

1.   He had his old trick of artless repetition, his helpless iteration of the obvious; but he was sensibly different, for Fleda, if only by the difference of his clear face, mottled over and almost disfigured by little points of pain.

2.   It made him angry, and all the more angry, that he hadn't a reason, to think of the charming creature at his side being mixed up with such elements, pushed and elbowed by them, conjoined with them in emulation, in unseemly strainings and clappings and shoutings, in wordy, windy iteration of inanities.