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A (MATHEMATICAL) TRIBUTE TO RONNIE BROWN: 1935 – 2024

Tim Porter

Résumé. Une esquisse de la vie de Ronnie Brown ainsi que quelques aspects importants de son œuvre et une liste de ses publications.
Abstract. We provide a sketch of the life of Ronnie Brown, presenting some important aspects of his work and provide a list of his publications.
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Ronald (Ronnie) Brown, who was a prolific researcher and a frequent contributor to the categorical and topological literature, died on 5 December 2024, aged 89. He was also well known as a populariser of mathematics and an innovator in teaching the subject.

Ronnie Brown was born on 4 January 1935 to parents who were first generation emigrés to the U. K. from Romania. Aged about six, he spent some time in the USA, staying with family, whilst his father was in the army. Coming back to the UK in 1944, his family moved around quite a bit, but, eventually, Ronnie went to Alleyn's School, Dulwich, London, where his interest in mathematics was encouraged. He gained a place in New College, Oxford, in 1953. In Oxford, he met Margaret, also a student of mathematics. They married in 1958 and later had eight children.

After completing his undergraduate degree at Oxford, Ronnie started as a postgraduate, again at Oxford, where his supervisor was Henry Whitehead.

Professor Whitehead died suddenly in 1960 and Ronnie continued under the supervision of Michael Barratt. His thesis title was '*Some problems in Algebraic Topology: A study of function spaces, function complexes and FD-complexes*'. The title shows several aspects of Ronnie's research interest, not only in algebraic topology, but also in what is now seen as part of the categorical side of topology. That latter area was exemplified, from the start, in the subject matter of his first two papers, [R1, R2], published in 1963 and 1964, which discussed properties of various topologies on products of topological spaces, and the corresponding relationship with function spaces and product topologies, especially with regard to the crucial 'exponential law',

$$X^{(Y\times Z)} \cong (X^Y)^Z,$$

for function spaces. Much later, when Ronnie was attending an international category theory meeting[1], he was surprised to discover that these, his first two papers, were considered of foundational importance for a large area of categorical topology, and also for the study of non-cartesian monoidal structures on categories.

At that time, (1959 - 1964), Ronnie was an Assistant Lecturer, and then Lecturer, at Liverpool University. Slightly later, he became, from 1964 to 1970, a Senior Lecturer, then Reader, at the University of Hull. In 1968, he published a text book, '*Elements of Modern Topology*', [B1], which was to become very influential, both in the teaching of the subject, and in the direction that Ronnie's own research took subsequently. That book was revised and updated twice over a period of years, as [B3] and [B4], yet its contents and style, suitably evolved, still prove important for more recent generations.

It was while writing that book, and, as he said later, 'to clarify certain points relating to the calculation of the fundamental group of a circle', that he started taking an interest in groupoids. Significantly one of his two publications at this time, [R8], discussed the groupoid version of van Kampen's theorem, which extended the classical form to unions of *non-connected* spaces, and which allowed the direct calculation of the fundamental group of the circle, and more. The proofs suggested to him there might be higher dimensional versions of that theorem and the search for those was one of the themes of Ronnie's research for the next nearly 20 years.

[1] I think it was in Amiens.

In 1970, Ronnie moved to North Wales to take up the post of Professor of Pure Mathematics at the then University College of North Wales, part of the University of Wales. The family moved to Anglesey, to Benllech and to a house just a short distance from the beach.

From 1974 onwards, Ronnie started exploring the topic of higher dimensional analogues of the groupoid van Kampen's theorem, working with Phil Higgins, initially from King's College London, later at Durham University. This work also involved input from several postgraduate students, often in crucial ways, and also from other collaborators such as Hans Baues, and later Jean-Louis Loday. The main thrust of this research lasted over 20 years, culminating in the book, [B5], with Phil Higgins and Rafael Sivera. This collected up the interlocking theories related to the proofs of a higher dimensional form of van Kampen's theorem, but also the interactions of those new theories with other more classical themes. It also involved some ideas, especially those around *crossed modules* and what became known as *crossed complexes*, which had been developed by Henry Whitehead in the 1940s and 50s from ideas of both Whitehead and Reidemeister in the 1930s, but which had mostly lain fallow in the intervening period. The strong connection with Whitehead's work only became clear as the collaboration with Higgins progressed. This linked the new Brown-Higgins theory into the vision of Whitehead for an *Algebraic Homotopy Theory*.

At this point we should mention the highly influential paper, [R56], with Marek Golasiński, in which a Quillen model category structure was specified on the category of crossed complexes, as this started the exploration of the link between a Whitehead-style algebraic homotopy theory and the theory of model categories.

For Ronnie, there was a very interesting spin off from the study of crossed modules and crossed complexes. With Johannes Huebschmann, [R35], he examined pre-war work by Reidemeister and his student Peiffer on identities among relations in presentations of groups, pushing that theory forward in several ways. These relied on a detailed analysis of the notion of free crossed modules and their interaction with various concepts from combinatorial group theory. It also used earlier work by Ronnie and Chris Spencer, [R20] and [R21], giving the first published detailed proof of a theorem mentioned by Verdier and Grothendieck, which showed the link between internal categories in the category of groups and crossed modules.

As mentioned above, further collaboration, (1983-87), again within this general area of '*higher dimensional group theory*', occurred in collaboration with Jean-Louis Loday, and centred on his models for homotopy n-types, called cat^{n-1}-*groups* and crossed $(n-1)$-cubes of groups, which generalise internal categories in groups, and crossed modules respectively. Via a van Kampen style theorem for these models, the collaboration revealed a new type of tensor product-like construction available when two (possibly non-abelian) groups act on each other in a compatible way. This further lead to work with Dave Johnson and Edmund Robertson, [R52], on more purely group theoretic aspects of this theory, whilst work by Ronnie's former research student, Graham Ellis, and many others, pushed the theory forward, linking it with several important areas of group theory.

One of the papers with Graham Ellis, [R55], explored higher dimensional analogues of the famous Hopf formula, which gives an expression for the second homology group of a group on being given a presentation of the group. As with many of Ronnie's papers, this has been very influential, leading to many developments, this time in categorical and 'higher dimensional' algebra. These continue today nearly 40 years later.

Although that area of 'higher dimensional algebra' was an important theme of Ronnie's research, from about 1975, he also continued to work[2] on the theory and application of topological groupoids, extending ideas of Charles Ehresmann and Jean Pradines and interacting with ideas on foliations and orbifolds. Much of this later work focussed on the ideas of Monodromy and Holonomy groupoids, interacting with Kirill MacKenzie in Sheffield; see [R71], [R118], and [R145].

In 1982, Ronnie wrote a letter to Alexander Grothendieck, and this started a very fruitful and amicable exchange of letters, [L], that lasted until 1991. His motivation had been to ask Grothendieck about his interest in notions of ∞-groupoids and categories, as certain types of ∞-groupoids corresponded to crossed complexes. This motivated Grothendieck to follow up on some ideas he had had some years earlier and to start on the famous set of typed notes known as *Pursuing Stacks*, published in book form only in 2022, but distributed from Bangor with Grothendieck's permission, as a photocopy of

[2]with others, including ex-research students, Hardy, Aof, Mucuk and İçen; see the references.

the original as Grothendieck wrote it.

The models for (some) homotopy types that Ronnie was putting forward were *strict* ∞-groupoids and categories, corresponding to crossed complexes in one of their manifestations. They thus did not fully answer to all the requirements of Grothendieck's wider programme, which needed some weaker form of ∞-groupoids to handle *all* homotopy types. None-the-less this provided additional evidence of the importance of the Brown-Higgins theory of what they now started referring to as *nonabelian algebraic topology*, *c.f.* [B5]. This was seen as an intermediate stage between a classical *homological*, and thus *abelian*, methodology and the vision of the theory proposed by Grothendieck that aimed at modelling *all* homotopy types by means of *weak* ∞-groupoids. The work of Ronnie with Jean-Louis Loday also fitted into this overall perspective.

At about this same period, Ronnie was reminded of one of his earliest papers. In [R5], he had examined some methods introduced by Shih in 1962, for calculating with E. H. Brown's notion of a twisted tensor product that dated from 1959, and also the related results of Barratt, Gugenheim and Moore from the same year. This was for examining the structure of the homology of the total space of a fibration in terms of the homology of the base and fibre of the fibration. Slightly later, in 1972, Gugenheim rediscovered these results and the two papers together came to form the basis for what is now called *Homological Perturbation Theory*. This has turned out to be an important theoretical and computational tool, and with computational input from Chris Wensley and Larry Lambe, Ronnie started on adapting various computer algebra packages with the aim of obtaining insight into the structure of algebraic homotopical invariants and algebraic homotopy types using methods from combinatorial group theory, and also from the theory of Gröbner bases; see [R101, R113].

Although this is not exhaustive as a description of Ronnie's research interests, rather than continuing with more such, we will pause and leave the reader to peruse the list of his research papers, noting how the various themes, topological and categorical, theoretical and computational, intertwine and interact throughout his research. We will return to this later on, but considering his impact on other aspects of the subject area, it would not be correct to omit either his work in popularisation or on teaching innovation.

Moreover these activities interacted with his research interests.

Ronnie's involvement in the popularisation of mathematics is well known. In about 1985, with a group of colleagues and with the assistance of local schools in North West Wales, he initiated a series of Mathematical Masterclasses for Young People in the area, under the aegis of the Royal Institution of Great Britain. This led to the development in Bangor of material that was designed to be useful in some of those Masterclass sessions, and also to the preparation of a set of exhibition boards on the theme of 'Maths and Knots' for use when giving talks in the masterclasses, and, increasingly, elsewhere; see [PP3].

Very quickly, this project was to acquire another component. As Ronnie says in [PP1]: '*One day in May 1985, I was walking down Albermarle Street*[3] *from a meeting on masterclasses at the Royal Institiution. As I passed the Freeland Gallery, ... and with some time to spare, I decided to wander inside, enticed by the sculptures of children and animals shown in the window. To my amazement I found also some strong and beautifully crafted knot sculptures*'. Thus started a collaboration and friendship between Ronnie and the sculptor, John Robinson, and a widening out of the scope of his popularising work on the theme of 'How Mathematics gets into Knots'. This led to Bangor's involvement in the *Pop Maths Roadshow*, and in a pan-European project on *Raising Public Awareness of Mathematics* for European National Science Week, 2000. This involved lots of fun interaction with lots of interesting people ... and a lot of thought and hard work!

Partly as a result of working with the younger students in the masterclasses, and with the general public through popular lectures and the exhibition, Ronnie, with myself and others, started thinking about the *context* of the mathematics that was being taught to our own students. We realised, for instance, that even our own students were not really aware that new mathematics was being discovered / created all the time, nor how that was done. We felt '*We should also popularise mathematics to (our own) students*[4]', as an antidote to the pressures for undergraduate courses to become 'a bare skeleton of technicalities', rather than an exciting endeavour involving human interaction. We thus developed a new type of course: 'Mathematics in Context'. The style was very informal and in [T3], we describe the reac-

[3] in central London

[4] from [T18]

tion of the students. We discussed historical, cultural and scientific issues, and got very good and interesting input and feedback from the students. The course did evolve in the years that followed with use of some external speakers, for instance from industry, and with colleagues describing and discussing some of their research projects in talks at the level of ones for a general educated audience. The sessions were very enjoyable and were, in general, very well received by both the students and, when the assessment was completed, by the external examiners for the degree.

The idea of adding 'context' explicitly into courses was addressed in [T18], and interacted with discussions on the *methodology of mathematics*, which coalesced in published versions, for instance, [T6, T7, T11], and [T20]. The multiple versions were due to requests from various sources to republish the original paper in their own journals for local consumption, as the originals had not always been that easy to find.

This emphasis on methodology and on making research more approachable started to feedback into Ronnie's research. It meant that he had a very clear idea on how to explain methodological ideas to non-mathematicians, partially bridging the well known gap between a mathematical view and the viewpoints of scientists from other branches of enquiry.

Running through Ronnie's research, there are some themes that repeat, and these also pervade other branches of science. One is the idea of '*local to global*', so how 'local' information about an object coalesces to give global information. Another, which is almost the converse of that, was the idea that '*subdivision is an inverse to composition*'. For Ronnie, the local to global paradigm was exemplified by the various higher algebraic structures that grew out of the quest for generalisations of van Kampen's theorem, but at the same time, how that worked involved a detailed analysis of cubical subdivisions. The local to global aspect provided insights into various philosophical and scientific questions, which were illustrative of the methodology of mathematics, for example, abstraction, modelling geometric situations via algebra, and the development of new concepts.

In discussions, he realised how these paradigmatic problems were important in other very interesting areas. In computer science, for instance, the local to global problem interacted with ideas on concurrent computing in a very geometric way, whilst ideas on 'composition versus subdivision' led to discussions on modelling neuro-systems, and more general hierarchical sys-

tems in biology and biocomputing. Philosophical / psychological contexts in which the problems of abstraction and the refinement of concepts occurred, also mirrored quite closely those encountered in mathematics. These discussions led to several papers involving Ray Paton, [R90, R111], of the Biocomputing and Computational Biology group at Liverpool University. This direction was cut short by Ray's untimely death in 2002, but was taken further with different emphasis in joint work with Jim Glazebrook and Ion Baianu, for instance, [R116, R123, R126] or [R138].

Throughout his life as a research mathematician, Ronnie served in editorial roles for international journals. From 1975 to 1994, he was on the editorial advisory board for the London Mathematical Society. He was a founding member of the editorial board of *Theory and Applications of Categories*, then on the editorial board of *Applied Categorical Structures*. In 1999, he helped found the electronic journal, *Homology, Homotopy and Applications* and then, from 2006, was an editor for the *Journal of Homotopy and Related Structures*. In 2016, a special volume of that journal was dedicated to him and his work on the occasion of his 80th birthday.

Throughout his career, he supervised many postgraduate students, who contributed greatly to the various research themes of interest at Bangor. In all there were 24 such, as listed by the Mathematics Genealogy Project. With many of these he developed long lasting collaborations as can be seen from the publication list.

Ronnie retired from full time teaching in 1999, although he continued as a half-time research professor until 2001. This, of course, did not reduce the amount of time and effort he put into his research and in particular into the preparation of the book, [B5], with Phil Higgins and Rafael Sivera, which regrouped the results from the long series of articles with Higgins, developing their theory in a coherent way in one source. He also developed new collaborations as Coordinator for an INTAS funded project, 'Algebraic K-theory, groups and categories', linking Bangor, with the University of Bielefeld, the Georgian Mathematical Institute, the State Universities of Moscow and of St. Petersburg, and the Steklov Institute, St. Petersburg. This involved research visits to Bielefeld and visits of their team to Bangor.

In 2016, Ronnie was elected to Fellowship of the Learned Society of

Wales and he was a lifelong member of the London Mathematical Society.

By about 1998, Ronnie had become hard of hearing on one side, and during one of the visits to Bielefeld for discussions with Tony Bak, he suffered from a severe loss of balance. On his return to North Wales, he was diagnosed as having an acoustic neuroma, which is a non-cancerous growth covering the acoustic nerve. He was treated for this in February 2000, and for a time was feeling a bit better. He then began to suffer from double vision. This was caused by some of the debris from the treatment of the neuroma. This itself was treated in 2001, and he gradually recovered and continued to work on his research projects.

Although he and Margaret had eight children, throughout his life he had found time to play firstly table tennis, then later on squash and to go swimming, both in the sea and in the lakes of North Wales. He also spent time gardening, making home made beer, searching for mushrooms in season, and exploring the region with the children when they were young.

On retirement, he and Margaret left Anglesey to move to Deganwy, near Llandudno, still in North Wales, and to a house with a beautiful view westward along the coast. They also had a small cottage for family reunions, and went on several Mediterranean cruises, including one during which he was roped in to explain some aspects of Greek mathematics! They both participated in the cultural life of the area.

Margaret died in 2020, and Ronnie's mobility had become reduced after a stroke. He was cared for by their eldest son, and enjoyed excursions using a mobility scooter, including to see seals in a cove a short drive away from their home, to visit a nature reserve on the Conwy estuary or the beautiful gardens at Bodnant, a short distance south along the valley of the river Conwy. It was after one of the visits to see the seals that he passed away peacefully, but suddenly, at home in Deganwy, aged 89 years. He will be missed by his seven surviving children, and his grandchildren.

Perhaps the last word should be left to his children who said that on journeys, their father would often deviate from the main roads to "take the scenic route" – sometimes getting lost in the process. But his attitude to life

and, in particular, to mathematics was always "take the scenic route". That love of exploring ideas or places for their own sake permeated his life both in his research career and in the teaching that he loved.

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Timothy Porter,
(ex. University of Bangor),
Ynys Môn,
North Wales, U.K.

t.porter.maths@gmail.com