Katherine G. Johnson (Taraji P. Henson) and Al Harrison (Kevin Costner) in Hidden Figures.

Hidden Figures and the Impact of Mathematics

The 2016 film *Hidden Figures* tells the powerful story of a group of female African-American mathematicians who worked on the first US space programme. Early in the film, the head of the programme, played by Kevin Costner, calls for an expert in analytic geometry when it becomes apparent that his team are unable to calculate the trajectories needed for safe re-entry of the first US space flights. His assistant, played by Kirsten Dunst, assigns Katherine Johnson (Taraji P. Henson) to the project. Johnson, a remarkable student who had graduated from university aged 19, and joined the space programme fifteen years later after a career as a teacher, spots that a numerical approximation technique will do the trick, rushes off to mug up the relevant textbook, and the team of human computers, led by Dorothy Vaughan (Octavia Spencer) get to work. With the arrival of an IBM mainframe, Vaughan leads a skunkworks project to teach her team Fortran, and so they are ready for the next challenge – the computation of the trajectories for the 1962 space flight which made John Glenn the first American to orbit the Earth. The movie was nominated for three Oscars in 2017, and Johnson herself, aged 99, appeared on the Oscars stage to wild applause.

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Spoiler non-alert: the movie is a dramatic tale of the impact of mathematics, even if its main point is something else. And it is impact on major industry sectors like defence, transport, construction, communications and finance that underpins the estimate by Deloitte [1] that 10% of all UK jobs and 16% of total UK GDP is a direct result of mathematics. Yet mathematics scores less well than other sciences on standard measures of knowledge exchange, such as patents and contract research. This is a concern in an increasingly metrics-conscious world, which leads some to question whether enough is being done to exploit mathematical research, and others to counter that such metrics are not appropriate for mathematics.

Mathematicians have long argued that the impact of mathematics is long term, hard to predict, and often happens via interdisciplinary work, and that audits of the process based on artfully constructed case studies, like those used in the UK's Research Excellence Framework (REF), a regular national assessment of research, may earn high scores, but miss the bigger picture. Some have gone further, arguing vehemently against the very concept of *impact*, and pointing out that the biggest impact of all, ignored by the REF, comes through effective education of students.

A recent paper [2], by Laura Meagher, a senior research evaluator, and me (a mathematician turned computer scientist with considerable experience in crafting submissions, and acting as a national assessor, for exercises like the REF), tackled this head-on. We used the qualitative methods of social policy researchers, and the trove of material provided by the 2014 REF, to dig into 209 published REF case studies of the impact of UK mathematics and statistics, and 52 REF impact templates (these describe mechanisms used by departments), complementing this with surveys, focus groups and in-depth interviews. We considered two basic questions – what kinds of impact does mathematics have, and how does that impact come about?

We drew on a categorisation of impacts originally developed for the human sciences which includes, alongside direct *instrumental impacts* of a particular piece of work in a particular application, the *conceptual impacts* that can reshape a whole field, *capacity building* impacts through education and training, *attitude or cultural change* and the *enduring connectivity* of long-term relationships with research users. While interviewees often felt that the REF drove them towards the *instrumental* impacts, which indeed dominated the case studies, our research showed that the broader categorisation was a good fit to mathematics, and indeed such broader themes were represented in the REF guidelines of some other disciplines.

Turning to mechanisms for impact, we identified the importance of mathematics focused *knowledge intermediaries*, who build bridges between the academic mathematics community and users of research. Examples include the UK's Industrial Mathematics Knowledge Transfer Network, study groups with industry to share problems and techniques, and individual mathematicians with the experience and human skills to nurture and develop trusted long-term relationships with external users of research, so that the right academic colleagues can be brought in quickly when an opportunity arises.

NASA research mathematician Katherine Johnson at the NASA Langley Research Center. Credit: NASA.

Our study confirms the importance of such long-term, informal relationships, often via another discipline, as vectors for impact, and the importance of routes such as software, seminars and secondments, as well as published research papers, for transmitting expertise. We also reinforce the crucial importance of developing a culture supportive of research and the generation of impacts which reinforces the distinctive but all-pervasive nature of mathematics. Indeed, reading across our 209 case studies emphasises that they are windows onto a complex ecosystem of research and research users: the more complex the system, the easier it is likely to be to extract linear narratives of the kind required by the REF, but the less representative of the true picture such narratives will be.

On 5 May 2016, NASA Langley's new computer research lab was named the Katherine G. Johnson Computational Research Facility.

At the event, Katherine Johnson received a Silver Snoopy award from astronaut Leland Melvin. Often called the astronaut's award, the Silver Snoopy goes to people who have made outstanding contributions to flight safety and mission success.

Credit: NASA | David C. Bowman

Katherine Johnson (Taraji P. Henson) and fellow mathematicians meet the man they helped send into orbit, John Glenn (Glen Powell).

Johnson's name first appeared on a NASA publication in 1960 – the technical report *Determination of azimuth angle at burnout for placing a satellite over a selected earth position* [3] cites two earlier internal technical reports, and a 1914 textbook on celestial mechanics. Google scholar finds minimal citations. Much head-scratching no doubt for a hypothetical bean-counter trying to shoehorn the space programme into the framework of a case study showing the impact of mathematics. Did the technical reports display sufficient *originality, significance and rigour*? Was the textbook published in the required time-window? Were the Fortran programmes, and the protocols for hand-calculation which preceded them, eligible to be counted as *research outputs*? Indeed, how could the impact of the space programme on *health, wealth and quality of life* be evidenced and quantified?

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While older readers may remember long-running gags about materials developed for rocket nose-cones being used for non-stick saucepans, US investment in the space programme led to advances in computing, communications and electronics; new understanding of physiology; and fundamental discoveries about the origin of life from the analysis of the rocks brought back from the moon.

It is probably a bit self-indulgent to look to *Hidden Figures* for confirmation of our research findings. But there in plain sight are the *conceptual impact* of using a numeric rather than an analytic technique; the *instrumental impact* of improvements in how the calculation was carried out; the *capacity building* of training some of the first programmers; the *attitude or cultural change* of the managers towards both previously marginalised groups of mathematicians and the value of computational techniques; and the *enduring connectivity* of long-term relationships between the space programme and the universities attended by Johnson and the rest. At various times the Costner and Dunst characters, and Johnson and Vaughan themselves are *knowledge intermediaries* alongside other roles, and one of the main themes of the film (but to go into this further would certainly be a spoiler) is the Costner character's commitment to a *culture supportive of research and the generation of impacts*; the culture that enables the remarkable contributions of Johnson and her colleagues.

Watching *Hidden Figures* reminds us that dry chains of citations and formulaic templates are not the only ways to convey the impact of mathematics. Finding new and creative ways to tell the story of the importance of mathematics will surely inspire other hidden figures to create new mathematics and new impacts. If that means a few more great movies who's going to complain?

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