Institution: Goldsmiths, University of London		
Unit of Assessment: 11, Computer Science and Informatics		
Title of case study: Mutator: A unique artistic collaboration creating new ways to experience and understand science		
Period when the underpinning research was undertaken: 2005-present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
William Latham Frederic Fol Leymarie	Professor in Computing Professor in Computing	2007 – present 2004 – present
Period when the claimed impact occurred: 1st Sept 2013 to 31st Dec 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

Virtual reality (VR) is a ground-breaking technology in principle, but in practice most of its applications have been inspired by established cinematic and gaming forms. Goldsmiths' Computing Department has provided the milieu for a cross-disciplinary collaboration which brings together visual art, software engineering and scientific modelling to create a suite of highly original VR experiences with deep and diverse social and scientific impacts.

William Latham and Frederic Fol Leymarie's Mutator platform enables users to immerse themselves in experientially rich virtual landscapes, based on rigorous mathematical modelling of biological systems. This has led to the creation of a family of pioneering VR experiences that are evocative (as art), illuminating (as scientific visualisations), educational (as models of biological processes) and entertaining (as immersive games).

These have secured deep engagement with international cultural audiences, found significant real-world applications in science and more recently attracted significant commercial interest.

2. Underpinning research

William Latham pioneered the use of evolutionary algorithms – those that mimic biological processes – in computer graphics at IBM's UK Scientific Centre in the late 1980s and early 1990s. The products of the FormGrow system were appreciated both as art (exhibited in galleries) and in popular culture (via the "rave" scene) but rooted in rigorous mathematical modelling by the biologist William Hamilton and software engineering by computer scientist Stephen Todd. Frederic Leymarie founded Goldsmiths' pioneering MA in Computational Arts and in 2005 invited Latham to present his work. That began a process of increasing engagement and collaboration which culminated in Latham becoming a professor at Goldsmiths in 2007.

Computer art: The initial focus was to reimplement, update and expand FormGrow, the result being the Mutator modelling and visualisation platform. Mutator has been used to create a range of experiences with diverse applications, but which all allow their users to generate and explore limitless new worlds. **[R1]** These environments, and their simulated inhabitants, react and develop according to accurate biological principles. **[R2**] The initial screen-based presentation was implemented as a series of immersive virtual reality environments from 2016 onwards.

Visualisation: Because the system renders millions of points of scientific data into a custom model, controlled by a novel but carefully designed user interface using standard VR hardware, it became apparent that the platform could also support scientific visualisations if applied to actual biological systems. Latham and Leymarie, working with collaborators at Imperial College, Oxford University and the University of York, developed systems – FoldSynth and CSynth **[R3,R4]** – which give both laypeople and researchers an intuitive way to explore and understand the structure, composition and function of biological molecules, including DNA, proteins and entire viruses such as SARS-COV-2.

Outreach: The visualisation work found substantial application in public outreach, which became the focus of a subsequent project with Imperial College. Between 2013 and 2017, the partners developed BioBlox an educational game allowing laypeople to explore how proteins "dock" with each other, as well as 3D graphical tools for scientists. **[R5]** This work was funded by a four-year, £1m BBSRC grant and is now being expanded to illustrate the molecular mechanisms used by Covid-19.

The common strand through each of these four areas of development is the combination of intensive data modelling, a novel interface and gamification, applied to both real and simulated biological systems. There is also a shared emphasis on cross-disciplinary collaboration, rapid prototyping and development through iteration – a combination uniquely facilitated by the culture and objectives of Goldsmiths' Computing Department. **[R6]** Typically Latham works with collaborators to identify realisable areas of mutual interest; Leymarie supplies the mathematical modelling and Todd the software engineering needed to implement it. Releases are driven by outreach at public events, which allows feedback to be gathered and acted upon quickly, as well as attracting further collaborators.

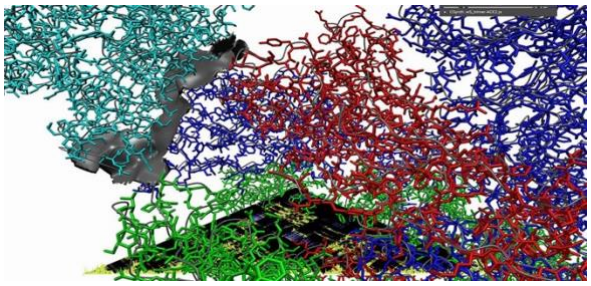

Image from the MutatorVR CSynth software showing the medial surface between a human cell (in light blue) and Covid-19 virus spike at protein level, in VR

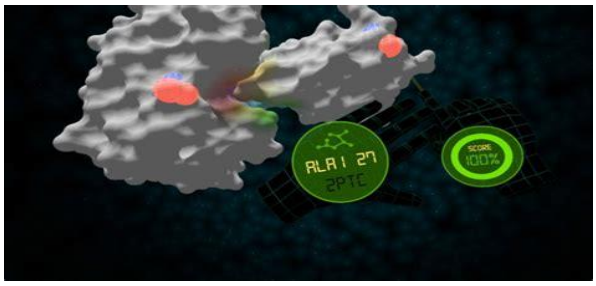

Image from the Bioblox game showing a player attempting to locate a protein docking site

3. References to the research

R1. Putnam, L., **Latham, W**., & Todd, S. (2017). Flow Fields and Agents for Immersive Interaction in Mutator VR: Vortex. *Presence: Teleoperators and Virtual Environments*, 26 (2). 138-156. DOI: 10.1162/PRES_a_00290

R2. Latham, W., Shaw, M.,Todd, S., **Leymarie, F.F.,** Jefferys, B. & Kelley, L. (2008). Using DNA to generate 3D organic art forms. In Giacobini M. et al. (eds) *Applications of Evolutionary*

Computing, *Evo Workshops 2008. Lecture Notes in Computer Science*, vol 4974. pp. 433-442. DOI: 10.1007/978-3-540-78761-7_46
R3. Todd, S., Todd, P., **Leymarie, F., Latham, W.,** Kelley, L., Sternberg, M., Hughes, J. & Taylor, S. (2015). 'FoldSynth: Interactive 2D/3D Visualisation Platform for Molecular Strands'. In: *Eurographics Workshop on Visual Computing for Biology and Medicine* (VCBM), Chester. DOI: 10.2312/vcbm.20151207
R4. Todd, S., Todd, P., McGowan, S., Hughes, J., Kakui, Y., **Leymarie, F.F., Latham, W**. & Taylor, S. (2020). CSynth: An Interactive Modelling and Visualisation Tool for 3D Chromatin Structure. *Bioinformatics,* btaa757. DOI: 10.1093/bioinformatics/btaa757. [Submitted to REF2]
R5. Thomason, A., Leyton, PQ., Filippis, I., Sternberg, M., **Latham, W. & Leymarie, FF**. (2016) "BioBlox: Protein Docking Game" (2016), presented at VizBi, EMBL Heidelberg, Germany.
R6. Lai, G., **Latham, W. & Leymarie, F.F.** (2020). Towards Friendly Mixed Initiative Procedural Content Generation: Three Pillars of Industry. FDG '20: International Conference on the Foundations of Digital Games, 11, p.1-4. DOI 10.1145/3402942.3402946

***All outputs available online/on request**

4. Details of the impact

1: Large and diverse audiences for a new form of art

Image: Mutator VR Vortex exhibited at the Kinninji Buddhist Temple in Kyoto, March 2019

Mutator VR allows users to create and explore virtual landscapes that are procedurally generated from mathematical rules and inhabited by organisms which obey biological principles. Each experience is unique as users explore endless worlds, unseen and unheard until called into existence. There are now several variants – Vortex, FormScape and Tadpoles – which explore different permutations of interaction with the environments and their occupants. **[S1]**

These new artefacts have been continuously exhibited at major international cultural venues. For example, during 2019/20 they were featured in public exhibitions at such globally renowned institutions as The Lowry in Manchester; the Pompidou Centre in Paris; the Hermitage in St. Petersburg, the Modern Art Museum in Shanghai. They have also appeared in numerous less formal locations, ranging from the Shoom 30 rave to the New Scientist Live science festival and the Kennin-iji Buddhist Temple in Kyoto. **[S2]**

This has exposed the work to a far larger and more diverse audience than is typical for computer art. For example, at New Scientist Live, 2,300 people experienced MutatorVR for themselves, while its presence as an "anchor" exhibit with large-scale projection meant it would have been apparent to all 25,000 visitors to the event. This is all the more impressive given the challenges of mounting such exhibits.

"Taking VR artworks in exhibitions like the public realm festival Lightwaves 2018 and gallery exhibition The State of US [at The Lowry, Manchester] both have challenges. They both produce a high footfall of public engagement and the artworks have to adapt to high levels of audience interaction whilst also producing a rich artistic interaction for the public," says Lucy Dusgate, the producer at The Lowry responsible for Mutator's appearance in both these shows. "Working

closely with Professor Latham enabled us to jointly develop and adapt the artwork to address these key issues … We were particularly impressed and received public feedback that the artwork was engaging for all ages, social demographics and produced an accessible and seamless high-quality experience for audiences. It effortlessly created a learning environment that captivated curiosity and encouraged broad participation in the learning." **[S3]**

This appeal has proven to be globally applicable, even in cultures that might not be considered receptive to VR art. "Asians prefer expression of the world so that it looks like nature in our real world rather than a pure virtual world. Therefore, it is a big challenge for [Latham] and me to exhibit the Mutator VR in Japan," writes Naoko Tosa of Kyoto University. Nonetheless, it was shown at Kyoto's oldest Zen temple, where "interestingly and fortunately against our worry, most of the visitors … appreciated the exhibition. This means the worldview expressed by the Mutator VR is global and could be understood and shared by people over the world." **[S3]**

2. Illuminating visualisations help scientists share their research

Molecular biology deals in microscopic entities – proteins, genes, viruses – whose structures are enormously complicated and whose behaviour is radically unintuitive. It thus presents a challenging communication problem, despite its fundamental importance and applications in healthcare.

"A significant outcome of this work meant we developed several high-profile public engagement experiences with CSynth at the core. This work was initially funded by a Wellcome Trust Public Engagement award and called “DNA Origami: How do you fold a genome?” and resulted in worldwide coverage and exposure of our research to thousands of members of the public," says Stephen Taylor, Head of the Computational Biology Research Group at the MRC Weatherall Institute of Molecular Medicine, University of Oxford.

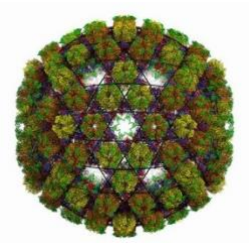

Image: MVR CSynth Virus Viewer displaying the Herpes Simplex Virus in VR

Visualisations of protein docking and of viral structures have been shown to the general public at high-profile outreach events including New Scientist Live, the Imperial Spark Festival, the Royal Society Summer Exhibition, the Cheltenham Science Festival and at the Crick Institute to inform public understanding of scientific research. Inclusion in these events is highly competitive and selected work must be scientifically rigorous while also accessible to the public. **[S4]**

"The Virus VR set up to illustrate our latest research in the modelling of viruses based on our paper “Structural puzzles in virology solved with an overarching icosahedral design principle” on virus tilings in the journal Nature Communications in 2019 … has been very well received by the general public and has changed their perception of the importance of Mathematics in Virology as the feedback forms demonstrate," writes Professor Reidun Twarock of the University of York, including comments such as “A clear visual look at mathematical structures in biology” and “I didn’t know how important mathematics were in understanding viruses before I used the VR”.

"Such outreach projects that are designed to change perceptions on the impact of mathematical research in virology are even more important at present in view of the current Covid-19 pandemic, as they illustrate the contributions academia is making to the health sector, and highlight the solutions that science has to offer to society." **[S5]**

3) Educational games inform young people’s understanding of how viruses work

Bioblox is a free mobile game for young people, ages 11-18, which demonstrates how proteins dock. Users drag, rotate and swipe to move protein shaped ‘jigsaw pieces’ around the screen in a manner akin to Tetris. This is an important problem in molecular biology and understanding it

is key to developments in medicine and public health, as testified to by the £1m in funding granted to the project by the BBSRC. **[S6]**

This topical game has been endorsed by games industry bodies Ukie and TIGA. The latter's CEO, Richard Wilson noted: "It is timely to see Goldsmiths and Imperial Researchers using games technology to promote understanding of the corona virus, medical science and social distancing in a very novel way". **[S7]** The game was rated the second-best educational app for Android by Science Focus magazine in September 2020.

The collaboration's public-facing, iterative approach to research and development has led to continuing collaborations with an increasingly diverse set of partners. For example:

- Showing the work in Shanghai led to a Visiting Professorship for William Latham at Jiao Tong University and the commissioning of a major "Master Studio" retrospective exhibition and lecture series, funded by JTU, to be delivered in 2020/21. **[S8]**

- Exhibiting MutatorVR led to discussions with the R&D division of hardware manufacturer HTC Vive. This has in turn led to a memorandum of understanding with the University of Maryland to investigate if MutatorVR can be used in pain relief for medical patients. **[S9]**

- Work done on virus modelling with partners at the University of York under a Wellcome Trust award is now underway to turn genetic information into musical notes. The objective is to create an instrument that will simultaneously play music and simulate genetic mutation, illustrating this important concept in an accessible way. **[S10]**

- Adding generative audio to the MutatorVR set-up has created a compelling but highly intuitive creative platform combining sight, sound and movement. This has attracted substantial interest from major music labels and games companies and is being prepared for spin-out as a standalone commercial company.

5. Sources to corroborate the impact

S1. The Mutator VR website - overview of the work and its history, including extensive documentary images and videos.
S2. Full list of exhibitions for Mutator evidencing the reach and dissemination to audiences
S3. Curator testimonials appraising project – a) Lucy Dusgate, The Lowry, Oct 2020; b) Prof. Naoko Tosa, Kyoto University, Sep 2020; c) Evelyn Wang, Modern Art Museum, Shanghai, Nov 2020. [Grouped Source]
S4. Evidence of contribution to leading cultural festivals - a) Programme, New Scientist Live (2016); b) Report, Wetherall Institute of Molecular Medicine, University of Oxford: 1. Royal Society Summer Exhibition 2017 Evaluation and 2. Cheltenham Science Festival 2018 Evaluation. [Grouped Source]
S5. Scientific outreach testimonials – a) Prof Reidun Twarock, University of York, Oct 2020; b) Stephen Taylor, University of Oxford, Dec 2020. [Grouped Source]
S6. Grant - evidence of sustainability; BBSRC for Bioblox work, Development and marketing of protein docking games for the educational sector, BB/R01955X/1, £121,079, duration: 12 months, start date: 15 Oct 2018.
S7. Letters of support for CovidBlox Evidence of impact on Games Industry; TIGA and Ukie
S8. Contract - Evidence of impact on higher education, William Latham Master Studio at Jiao Tong University, Dec 2020.
S9. Impacting Medicine - MOU with University of Maryland for pain relief work, Dec 2020
S10. Grant – evidence of sustainability, Wellcome Trust outreach grant for musical virus.