Institution: University of South Wales

Unit of Assessment: B10

a. Overview

The Mathematical Sciences group at the University of South Wales (USW, formed in 2013 by the merger of University of Glamorgan and University of Wales, Newport) currently comprises 13 full and 2 part-time members of staff, ten of whom are returned in this UoA. All were previously employees of University of Glamorgan. Research in the Mathematical Sciences is aligned into three equally-sized themes: (i) Physical sciences and industrial mathematics; (ii) Biological, health and social sciences; and (iii) Data integrity and combinatorics. The first two themes are organised into a single Research Unit "Applied Mathematics and Statistics" (http://model.research.glam.ac.uk) while the third comprises its own Research Unit "Data Integrity and Combinatorics" (http://data.research.glam.ac.uk). Active researchers have protected time for research; 12 members of the Mathematical Science group have protected research time.

b. Research strategy

The major aim of the UoA over the previous 5 years has been to increase the number of active researchers within the Mathematical Sciences group. This aim has been achieved; 4 researchers (4 FTE) were returned in the 2008 RAE Applied Mathematics submission while 10 researchers (9.2 FTE) are included in the current submission. A combination of recruiting new research active staff and minor changes in the research direction of existing staff is responsible for this increase.

The University has a commitment to enhancing a thriving research culture facilitated through a comprehensive programme of investment, research staff and student development and professional administrative support, as outlined in the University's Research Strategy 2009-2014. This includes the 'University Research Investment Scheme' which offers approximately £400k pa through a number of schemes (modelled broadly on research council processes); both **Boswell** and **Walker** received funding through this source for research studentships during the assessment period. The Deputy Vice Chancellor (Research and Student Experience) works with the Central Research Office, which provides core support on all research-related matters, including proactive support with grant applications, the organisation of staff and student skills development and training seminars and research student administration.

Aligning with the University's research strategy, the UoA has been influenced by local and national initiatives, engaging with industrial partners where such opportunities have arisen (e.g. Tata Steel/Chorus Steel, HPC Wales, Fujitsu, OSTC Ltd, National Botanical Gardens Wales, GXS Ltd, and others - see also REF3a). Expanding this activity, by utilising existing expertise across the University, is central to the future plans of the UoA; in particular, by increasing the number of research students recruited (for example, via EPSRC Case Studentships or similar schemes) and developing Knowledge Transfer Partnerships (see REF3a).

The University is committed to collaboration; 77% of researchers throughout the University have engaged in collaborative activities with external organisations (Careers in Research Online Survey, CROS, 2013). Within the UoA, in addition to utilizing networks developed by individual researchers, wider collaboration arises via Wales Institute for Mathematical and Computational Sciences (WIMCS) and HPC Wales (see below), the latter providing facilities that are planned to be central to attracting and retaining industrial partners to achieve the above objectives.

In the medium term, the UoA intends to more fully integrate newly-appointed staff with established researchers, generating further collaborations and ensuring the sustainability of the three central research themes. This is planned to be achieved predominately through the recruitment and joint supervision of research students so that their population grows in line with the recent increase in researcher numbers and which should in turn raise research income for the UoA. However, collaboration via wider networks established by researchers will continue to be supported and encouraged.

Researchers in the Mathematical Sciences group place great importance on promoting research to inspire the next generation of mathematicians; our annual lecture and Royal Institution Masterclasses are such examples and have involved distinguished external speakers including Prof. C. Budd (Bath) and Prof. D. Spiegelhalter, (Cambridge). Additionally **Boswell**, **Perkins** and **Roach** have supervised Nuffield Foundation Research Placement projects.

c. People, including:

i. Staffing strategy and staff development

The UoA has experienced considerable growth in the number of research active staff during the assessment period through the appointment of **Farnell**, **Trevelyan** and **Walker**. High-calibre research students from the Mathematical Sciences group have also been appointed (Dr. Sian Jones - not returned, **Wyburn** from part-time to full-time). These strategic appointments have resulted in the replacement of non-research active staff by established or promising researchers who complement and expand on established research themes. This continues to build on the staffing strategy outlined in the 2008 RAE Applied Mathematics submission and aligns with the University's priority areas of supporting applied research.

Newly appointed researchers are assigned an experienced mentor and undergo biannual reviews with the group's head. The career development of staff is fully supported by the University, as set out in the key principles of the Concordat; as well as providing internal development opportunities for researchers, for example, by continually training staff on good practice in research supervision (attended by 70% of the University's researchers; CROS, 2013), the University works closely with a network of other HEIs to provide researchers with access to further opportunities to develop their skills. The Effective Researcher, Grad Schools, Welsh Crucible and Leadership In Action are good examples of collaborative provision utilised by researchers (over 90% of the University's researchers have adequate access to training and development opportunities; CROS, 2013). In November 2013, the University was awarded the HR Excellence in Research Award by the European Commission for the implementation of the Concordat to support the career development of researchers, demonstrating the University's commitment to meeting the needs of researchers and improving opportunities in terms of development and future careers. In the Mathematical Sciences group it is anticipated that within the next 5 years the appointments made during the current assessment period will have successfully supervised at least 4 Ph.D. students, further demonstrating the continual career development of researchers within the UoA.

Promotions to Readerships and Professorial appointments are made by the University's Higher Academic Awards Committee in response to research excellence and the University's strategic direction which is driven by local and national initiatives; in 2013 **Roach** was appointed to a professorial role as a consequence of his multi-disciplinary collaborative activities, thus defining a career path for others and establishing the importance placed upon applied research. Similarly **Boswell** was awarded a Readership in 2012.

The University and the UoA is fully committed to supporting equality and diversity, as demonstrated by its implementation of the Athena Swan charter and the Women in University Mentoring Scheme (WUMS).

It is intended to continue the successful policy of recruiting established or high-potential research-active staff complementing and strengthening existing research themes within the Mathematical Sciences group. This will ensure the continuity of the present research agenda over the medium and longer terms.

ii. Research students

Currently 13 research students, at various stages of their studies, are supervised by members of the Mathematical Sciences group and in excess of 25 research students have been supervised by members of the UoA during the assessment period. These students were recruited from the home and overseas markets with each student having at least two supervisors. Funding for these

students has been obtained from an extensive range of sources including EPSRC Case awards, KESS awards (from European Social Fund with an industrial partner) and industry (e.g. Fujitsu).

All new research students are encouraged to enrol on a newly-created 60-credit module leading to a Postgraduate Certificate in Research which provides Ph.D. students with a sound framework for developing their research; **Walker** leads a module that contributes towards this qualification. In the 2013 Postgraduate Research Experience Survey (PRES), 90% of the University's research students felt their research skills had developed during their studies, 5% above the national average. Further opportunities for postgraduate development have recently been made possible through the 2011 opening of the University's Postgraduate Research Centre which provides a multi-disciplinary learning space; **Walker** is a member of its advisory board.

Research student progress is formally monitored by the Research Committee which supports the research team, appoints examiners, and disseminates good practice in the delivery of research degrees to current and future supervisors. Administrative support is provided by the central Research Office.

Students typically undertake a low level of undergraduate teaching to develop further essential professional skills and are encouraged to attend and present at suitable conferences; these include annual faculty and university-wide research workshops, WIMCS supported events (e.g. Wales Mathematics Colloquia), and major national and international conferences aligned to the student's area of expertise (e.g. British Applied Mathematics Colloquia, British Combinatorial Conferences, SGAI International Conferences on Artificial Intelligence, International Mycology Congresses, International Conferences on Computers and Their Applications) along with several specialist postgraduate conferences (e.g. Postgraduate Combinatorial Conferences, FAIRS'10- Forum for Research Students).

Recently the Mathematical Sciences group has offered a Ph.D. shadowing program allowing those interested in postgraduate research the opportunity to spend time working alongside current research students. While this program is in its infancy, anecdotal evidence suggests it provides a realistic experience of the life of a research student. It is planned to continue and develop this initiative.

d. Income, infrastructure and facilities

During the assessment period, approximately £250K of funding has been secured with contributions from members of the Mathematical Sciences group.

Six CASE / KESS studentships funded by EPSRC / European Social Fund have been supervised during the assessment period (including **Roach**, **Smith**, Tatarinova – formerly FT, currently HPL), all with contributions from industrial partners, while two further research studentships through Fujitsu have been awarded (**Roach**, Tatarinova). The Royal Society and EPSRC awarded grants for travel and to host international visiting academics (Tatarinova, Shi – not returned). The Royal Society, the London Mathematical Society and WE-Hereaus Stiftung awarded funds to support national and international conferences organised by group members (**Smith**, **Farnell**). The Nuffield Foundation awarded several Research Placement bursaries (**Boswell**, **Perkins**, **Roach**) and Welsh Crucible awarded funds to raise public awareness of the use of mathematics in the life sciences (Tatarinova). Additionally, contributions from a £1.4M grant from European Commission Research Fund for Coal and Steel have been used to buy out 12.5% of **Roach**'s time.

The Mathematical Sciences group is based in a single building at the centre of the University's largest campus. All staff and research students have high-quality accommodation with individual networked desktop PCs installed with standard and specialist software and receive full professional IT support.

Access to high-performance computing facilities exists through HPC Wales, a five-year £44 million pan-Wales project providing world-class supercomputing performance to researchers and businesses. HPC Wales was established in 2010 in partnership with the St. David's Day group of

universities (Aberystwyth, Bangor, Cardiff, Swansea, USW), the University of Wales, the Welsh Government and Fujitsu; researchers are currently engaged with projects using this facility (see Impact Case Study for more details) and future research plans are based on this resource.

Following the recent merger creating USW, we intend to investigate potential future collaborations that may arise across the University (examples of which are described below) and apply for research income accordingly, for example, though the funding of research students.

e. Collaboration and contribution to the discipline or research base

The University has close collaborative links with the St. David's Day group of Universities while individual researchers utilise wider national and international networks. Specific to Mathematical Sciences this involves the Wales Institute for Mathematical and Computational Sciences (WIMCS), which was established in 2008. WIMCS supports and promotes events, seminars, conferences and workshops that provide researchers opportunities to create and maintain a thriving research culture; all researchers and most research students at USW have contributed to such events. **Boswell** (and until July 2012 **Wiltshire**) is a member of WIMCS's Research Committee. Further collaborative activities have also arisen through HPC Wales (described above) and additional opportunities for collaborative activities arise via the University's Commercial Services Office and the Research Office, as outlined in the University's 2009-2014 Research Strategy.

Numerous international visiting researchers have been hosted by the Mathematical Sciences group including Prof. G. Wang (Hangzhou Dianzi University, China, 2008), Dr. J. Vance (University of Virginia in Wise, USA, 2008), Prof. M. Basin (Autonomous University of Nuevo Leon, Mexico, 2009) and Prof. A. Thomas (University of Utah, USA, 2010 & 2011). Specific collaborative activity in each research theme is described below, along with new opportunities that have arisen following the merger creating the University of South Wales.

Research theme: Physical sciences and industrial mathematics

Continuing the Applied Mathematics submission to RAE 2008, there is a wide-ranging interest in applied mathematics with research in fluid mechanics, quantum magnetism and various technological applications of mathematics by **Farnell**, **Trevelyan**, **Walker** and **Wiltshire**. Additional work in control theory has been performed by Prof. Peng Shi (on sabbatical at Victoria University, Australia).

Much of **Wiltshire**'s work related to the integrability of non-linear partial differential equations using classical, non-classical symmetry methods and more generalised techniques, with particular reference to applications occurring in the general theory of relativity and relativistic fluid spheres, resulting in numerous publications. Further work with Shi and a research student on control theory (on particular Riccati matrix equations) produced 3 publications. Additionally, **Wiltshire** took a lead role in establishing HPC Wales, which involved significant collaboration with all other involved organisations (see above).

Trevelyan's interest has focussed on Newtonian and non-Newtonian fluids and he has published almost twenty papers that can be classified into three types: three as sole author on asymptotic solutions of reaction-diffusions, three with Prof. S. Kalliadasis (Imperial College, London) and collaborators on interfacial instabilities in thin films and the majority of the remaining publications with Prof. A. De Wit (University Libre de Brussels) and collaborators on chemo-hydrodynamic instabilities in porous media. **Trevelyan**'s research has mainly focussed on reactions in immiscible systems of the form $nA+mB \rightarrow C$, where n and m are integers, and has obtained small and large time asymptotic solutions. Further predictions on how reaction-fronts in such systems depend on diffusion coefficients have been made and confirmed in experiments. **Trevelyan** plans to continue work on hydrodynamic instabilities with collaborators including Dr. M. Mishra (Indian Institute of Technology Ropar, India), Dr. C. Almarcha (Universite´ d'Aix-Marseille, France), Dr. Y. Nagatsu (University of Nagoya) and Prof. A. D'Onofrio (Universidad de Buenos Aires).

Walker's interests lie in the mathematical modelling of liquid crystals and the mathematical

modelling and design of ultrasonic transducers. In collaboration with Prof. I. W. Stewart (Strathclyde), **Walker** has published four papers on various problems concerned with smectic liquid crystals that have applications in display technology, bi-layer lipid membranes and ultra-strong materials. Alongside Dr A. J. Mulholland (Strathclyde), **Walker** has published two papers concerning the design and modelling of two novel ultrasonic transducers. Both of these projects have been aided by experimental researchers (Centre for Ultrasonic Engineering, Strathclyde). **Walker**'s future work will focus on (i) modelling smectic C liquid crystals accounting for previously ignored phenomena such as permeation, compressibility and a full asymmetric viscous stress tensor and (ii) modelling ultrasonic transducers, with existing collaborators, investigating experimental and theoretical validation of novel transducer designs. **Walker** is also currently involved in a project modelling the growth delay of aggregations of cancer cells under various treatment regimes (with Dr. S. Hutchinson & Mr. M. Tesson, University of Glasgow).

Farnell has published extensively on quantum magnetism, focussing on ground- and excited-state properties of models of quantum magnetic systems that have been proposed as physical realisations of quantum computers. This research dealt with quantum phase transitions in a whole host of magnetic models and the prediction of their zero-temperature phase diagrams. In collaboration with a number of international researchers including Prof. R. F. Bishop, Dr. J. Parkinson (both Manchester), Prof. J. Richter, Dr. J. Schulenburg (both University of Magdeburg, Germany) and Prof. C. Campbell (University of Minnesota, USA), **Farnell**'s research employed HPC to carry out exact diagonalisations and coupled cluster method (CCM) calculations resulting in 15 refereed journal publications and one book. Future research will focus on simulations of quantum magnetic systems, in particular their time-dependent properties and "quantum information" by implementing high-order CCM calculations via HPC for bosons on optical lattices.

Theme members have acted as referees for many international journals and as external Ph.D. examiners. Shi sits on the editorial board of in excess of 20 international journals and is the founding editor-in-chief of International Journal of Innovative Computing, Information and Control. Presentations have been made at numerous workshops, seminars and international conferences including the European Liquid Crystal Conference, meetings of the American Physical Society: Division of Fluid Dynamics, British Applied Mathematics Colloquia (BAMC), Scottish Fluid Mechanics Meetings, Wales Mathematics Colloquia and Gordon Research conferences. **Walker** received travel grants from Royal Academy of Engineering and Groupe de Recherche. **Farnell** was co-organizer of the workshop "Quantum Magnetism in Low Spatial Dimensions" at the Physikszentrum, Bad Honnef, Germany (http://obelix.physik.uni bielefeld.de/%7Eschnack/conferences/WEH-504/) with funding from WE-Hereaus Stiftung. **Trevelyan** visited Dr. M. Blyth (University of East Anglia) to continue his work on thin films (LMS funding to Blyth).

Research theme: Data integrity and combinatorics

The Data integrity and combinatorics theme comprises five members of research staff; **Hunt**, Dr. Sian Jones, **Perkins**, **Smith** and **Roach**. In RAE2008, work in this theme was returned in *Computer Science and Informatics* but is now returned in the current UoA following minor changes in research direction.

Research during the assessment period has focused on a variety of applications of coding theory, general problems in combinatorics, applications of metaheuristic algorithms and work relevant to the efficient use of the radio spectrum. Changes in technology have meant that the emphasis of the radio work has moved from frequency assignment to the coding theory relevant to code-division multiple-access (CDMA) and frequency hopping systems. Applications of coding theory in biology have also received considerable attention.

Six research students have worked in the research unit during the assessment period, two new staff members have joined and there has been substantial collaborative work with Dr. R. Montemanni (Istituto Dalle Molle di Studi sull'Intelligenza Artificiale, Switzerland). During the assessment period, **Perkins** and **Smith** have together published eight journal papers (including

one with **Hunt** and one with Montemanni). Additionally **Smith** has published eight journal papers and two conference papers with Montemanni (four with other authors), **Perkins** has published four journal and two conference papers with Jones and others while **Hunt** has published four journal papers with **Smith**. These publications can be divided into four areas:

(i) In a continuation of previous work on variable length codes, **Perkins** and **Smith** (with a research student) have constructed variable length codes with the best known synchronization properties and no disadvantages in comparison with Huffman codes. Following previous extensive funding from BAE Systems, collaboration continued into the current period, while BAE Systems continued to implement previous work. Encouragement from BAE Systems to concentrate on CDMA and frequency hopping systems led to six journal papers with combinations of **Smith**, **Hunt** and **Perkins**. The work successfully demonstrated reduced interference in synchronized and partially synchronized radio systems and derived useful ways of re-partitioning sets of Hadamard matrices.

(ii) A new area of work was the application of coding theory to the construction of DNA codes for genetic bar codes, micro-array applications and DNA computing. This work successfully constructed many best known codes for these areas of application, and led to two journal papers by **Perkins** and **Smith** (one with Montemanni). This application of coding theory in biology has attracted considerable interest; the first paper published in the journal *Discrete Mathematics* was the journal's 16th most downloaded paper in 2011.

(iii) The collaboration of Montemanni and **Smith** allowed the fruitful combination of Montemanni's expertise in heuristics with **Smith**'s theoretical background to make contributions to areas as diverse as sequential ordering problems, crane scheduling in ports, radio frequency assignment, constant weight codes, DNA codes and permutation codes. Constant weight codes have application to the assignment of frequency lists in frequency hopping radios. **Perkins** and **Smith** demonstrated the need to extend the available study of constant weight codes from length at most 28 to lengths from 29 to 63 for the frequency hopping application, and published associated results, causing a re-awakening of interest in this topic and improved constructions continue to appear. The work on permutation codes is partly driven by their potential application to powerline communication.

(iv) **Perkins** has also applied her expertise in combinatorics to the theory of mathematical puzzles such as Sudoku. She has published (with others including Jones and **Roach**) four journal and two conference papers on this topic. Additionally, an intriguing application of these puzzles as erasure-correcting codes has been studied resulting in a publication with a research student. Planned future work includes investigating generalised Sudoku and combinatorial chess puzzles and their connections to graph theory.

Additional future planned work in this theme will focus on problems at the interface of coding theory and combinatorics. In particular, previous research will be applied to the problem of long term storage of massive quantities of data to be archived in DNA, the feasibility of which has been recently confirmed. International links are currently being extended - an eminent Canadian researcher is expected to visit in 2014 - and continued industrial collaboration is planned.

As well as external examining of Ph.D. students and regular refereeing of journal papers by all theme members, **Perkins** has been a member of the editorial panel for several special issues of *Discrete Mathematics*. **Smith** was the organiser of 2010 Wales Mathematics Colloquium (WMC). **Hunt**, alongside **Boswell**, is co-organiser of 2014 WMC.

Research theme: Biological, health and social sciences

The biological, health and social science research theme includes work by Prof. Jamal Ameen (not returned, on sabbatical at Kurdistan Regional Government, Iraq), **Boswell**, **Farnell**, Dr. John Hayward (not returned), **Roach** and **Wyburn**, focussing on mathematical ecology, applied statistics in the health sciences and modelling various phenomena related to social issues

including language use and specialist financial markets.

Boswell (with research students) has built upon his previous expertise to develop and refine models of the growth and function of fungal mycelia. This work has been reported in seven refereed journal publications (with international co-authors including Dr. F. Davidson, Dundee; Dr. M. Frisher, College of Mount St Joseph; and Dr. M. Roper, University of California). The formation of fungal cords and the application of fungi as agents in bioremediation were investigated, both of which were novel applications. Competition and combat in fungi was the subject of a further publication which included the first model capable of generating the non-transitive hierarchy known to exist in fungal species. **Boswell** intends to continue investigating the application of fungi to remediate landscapes using hybrid models. Additional work has been conducted in the sports sciences, extending results on pacing strategies in cycle races, and new opportunities have arisen to further this research with the Sports Science group at USW.

Continuing work in medical statistics that featured in the 2008 RAE Applied Mathematics submission, **Farnell** has performed research analysing cancer patients after radical treatment regimes and in medical image processing. In the former**, Farnell** investigated patient-reported outcome measures, quality of life and psychosocial morbidity measures in patients after radical cancer treatment. This research, with Dr. S. Davidson (Christie Hospital, Manchester), resulted in six publications. In terms of medical image processing, practical applications by **Farnell** have included the analysis of ophthalmic images with Prof. D. Wong (St. Paul's Eye Unit, Liverpool) and J. Mehta (Liverpool) and the enhancement of blood vessels in digital fundus photographs with Prof. S. Harding (St. Paul's Eye Unit, Liverpool). **Farnell** has also worked on the theoretical foundations of statistical calibration with Prof. A. Pickles (Institute of Psychiatry, Kings College) and Dr. C. Roberts (Manchester), so far resulting in a single publication dealing with the effects of measurement error in statistical models of shape. In future this research is likely focus on the calibration problem for imputation of trends in psychosocial behaviour in adolescents as well as the mathematical aspects of estimation of standard errors via multiple imputations.

Wyburn and Hayward have adopted an approach using system dynamics and differential equation models to investigate the decline and recovery of the Welsh language in Industrial and Post-Industrial Wales, and of French in 20th and early 21st century Canada. This research resulted in three refereed journal publications and further work is continuing developing cellular automata models. More recent work involving **Wyburn** and **Roach** has branched into an investigation of economic phenomena with a strong social element. Of special interest has been the collectibles market, the dynamics of which diverge greatly from those of conventional investments and which has hitherto been largely unexplored. **Roach** and **Wyburn**, in collaboration with Prof. H. Coombs (USW), have analysed the development and behaviour of contemporary collectible markets resulting in one refereed journal publication. More general work on market behaviour involving **Roach** - including collaboration on buy/sell trading decisions with a trading company operating in derivatives - is currently in progress with OSTC Ltd., Swansea. Further work by **Roach**, related to the automated generation of business rules for product data quality assurance, is also underway through a project with HPC Wales.

Theme members have supervised over a dozen research students and acted as external examiners at numerous UK universities. In addition to all members having international journal refereeing duties, since 2010 **Boswell** has been a member of the editorial board for *Network Biology* and until 2012 **Farnell** was sub-editor of *SCOPE online* (the magazine of the Institute of Physics and Engineering in Medicine). Hayward was co-organiser of a 2011 WIMCS-supported workshop “Modelling with System Dynamics: making sense of a complex world”. Presentations have been made at numerous workshops, seminars and international conferences including European Conference for Mathematical and Theoretical Biology, International Mycology Conference, International System Dynamics Conference and various Medical Image Understanding and Analysis meetings. For 2014, **Boswell** is on the scientific committee and is a mini-symposium organiser for the BAMC.