Using Constructive Research to Structure the Path to Transdisciplinary Innovation and Its Application for Precision Public Health with Big Data Analytics

Carolyn McGregor AM

> *When scientists are asked what they are working on, their response is seldom 'Finding the origin of the universe' or 'Seeking to cure cancer.' Usually, they will claim to be tackling a very specific problem – a small piece of the jigsaw that builds up the big picture.*
>
> Martin Rees
> Cosmologist and astrophysicist
> Astronomer Royal and Past President of the Royal Society

New approaches to complex societal challenges require a diverse mix of resources and skillsets from different disciplines to create solutions that are of a transdisciplinary innovation nature. The constructive research method enables the purposeful creation of methods, modules, tools, and techniques that have applicability well beyond the case study that motivated their creation. This research presents a bottom-up approach that follows a structured path to transdisciplinary innovation. A method is presented that demonstrates how a set of innovative research collaborations progress from disciplinary innovation to multidisciplinary innovation and ultimately onto interdisciplinary innovation. Anchored in overlapping computer science concepts, drawing on the constructive research methodology for purposeful synthesis and integration between the projects, a greater transdisciplinary goal can emerge. This method is demonstrated through a case study involving a set of big data analytics research projects involving diverse disciplines such as computer science, critical care medicine, aerospace, tactical operations, and public health. The resultant collective vision for transdisciplinary innovation that has resulted offers new approaches to maintaining individual wellness within communities across their entire lifespan on earth and in space.

Introduction

Transdisciplinary research has been described by Pohl (2010) as combinations of four characteristic features of transdisciplinarity: 1) issues of social relevance; 2) transcending beyond and integrating disciplinary paradigms; 3) engaging in participatory research to link abstract and case-specific knowledge; and 4) knowledge unity through synthesis leading to practices that promote common good for the socially relevant issue. This translates to transdisciplinary innovation when goods or services that create value emerge.

One complex societal challenge that has emerged in recent years is that of "precision public health". The term was coined in Australia by Tarun Weeramanthri in 2013 (Dolley, 2018) and is considered to be "a new field driven by technological advances that enable more precise descriptions and analyzes of individuals and population groups, with a view to improving the overall health of populations" (Baynam et al., 2017).

One key technological advance that has emerged as relevant for precision public health is big data analytics. Specifically focused on data with characteristics of volume, velocity, and variety, such as data streaming from medical devices, environment sensors, and GPS locators, big data analytics has generated optimism for the potential of its value for health research and interventions (Dolley, 2018). Analytics on big data can be performed at two different stages: 1) in real-time as the streaming data is arriving, known as stream processing, real-time, or online analytics and 2) with persistent historical data after the data has been stored through knowledge discovery or data mining (McGregor, 2013a; Palem, 2014). However, Dolley's (2018) review demonstrates several isolated examples of multidisciplinary and interdisciplinary research and innovation with big data analytics in health that have not been able to evolve to transdisciplinary research and innovation to more broadly create value for precision public health. A systematic approach is required to transcend beyond and integrate disciplinary paradigms to enable the broader impact.

Two research methods are used extensively in the creation or application of new computing and information technology approaches for use in differing domains: constructive research and action research. The constructive research method is a systematic approach that enables the purposeful creation of methods, modules, tools, and techniques that have applicability well beyond the case study that motivated their creation. It is a research paradigm widely used in computer science, mathematics, operations analysis, and clinical medicine (Kasanen et al., 1993). The focus is on the construction, with theoretical demonstration as well as practical implementations as valid outcomes of the research process. Action research, as the name suggests, involves taking action, evaluation, and critical reflection (Koshy et al., 2011). Within the context of computing and information technology research, it refers to taking the action of introducing a computing and information technology solution then evaluating and reflecting on its value. Action research has been demonstrated in transdisciplinary research with its participatory and collaborative focus used as a driver for the interaction between many disciplines along with the broad context of taking action on the broad transdisciplinary innovation (Djanibekov et al., 2012).

This article presents a bottom-up approach that follows a structured path to transdisciplinary innovation. A method is presented that demonstrates how a set of collaborative constructive research projects progress from disciplinary innovation to multidisciplinary innovation and ultimately onto interdisciplinary innovation. Anchored in overlapping computer science concepts – and drawing on the constructive research methodology for purposeful synthesis and integration between the projects – a greater transdisciplinary goal can emerge.

This method is demonstrated through a case study involving a set of research projects focused on big data analytics involving diverse disciplines such as computer science, critical care medicine, aerospace, tactical operations, and public health. The resultant collective vision for transdisciplinary innovation is new approaches for precision public health to maintain individual wellness within communities across their entire lifespan on earth and in space.

Where the Journey Began: Big Data Analytics in Critical Care

Critical care units provide care for patients in critical condition provisioned by complex interdisciplinary teams of healthcare professionals. The medical devices within critical care generate high-speed physiological data and are seen to be a significant untapped resource in healthcare today. For big data analytics to create value in healthcare, new robust big data infrastructures to support clinical research and real-time clinical decision support are required (McGregor, 2018).

One of the most significant perinatal health problems in industrialized nations is premature or preterm birth, which is defined as birth before a gestational age of 37 weeks. Neonatal intensive care units (NICUs) are complex critical care environments requiring real-time technologies correlating medical data from multiple sources to assist with the detection of the potential onset of complications of prematurity such as infection or damage to developing brain, lungs, or eyes (McGregor, 2013a). At the turn of the millennium, the author recognized that neonatal intensive care – and critical care generally – would benefit from what would become known as a big data analytics platform to enable a systematic, reliable, and scalable approach for the analysis of the big data in the NICU (McGregor et al., 2002). Ultimately, the Artemis project (Blount, 2010), named after the Greek goddess of childbearing, was born from constructive research that leveraged high-speed physiological data together with other electronic health record data from the neonatal intensive care unit at The Hospital for Sick Children in Toronto, Canada, for earlier onset detection of the development of multiple conditions by multiple premature and ill full-term infants in multiple locations. The constructive approach divides the research process into six phases (Kasanen et al., 1993), which are listed in Table 1 along the corresponding phases of the creation of the Artemis platform.

Table 1. Phases of constructive research undertaken in the creation of the Artemis platform

Phase	Constructive Research	Artemis Constructive Research
1	Find a practically relevant problem that also has research potential.	How can we provide healthcare professionals in critical care with new clinical insights on multiple conditions derived from the analysis of physiological data for multiple patients in multiple locations using multiple real-time streams of physiological data?
2	Obtain a general and comprehensive understanding of the topic.	Disciplinary understanding of current state of research for platforms to enable real-time analysis and synthesis of physiological data streams. Disciplinary understanding of the current state of research for physiological data behaviours prior to the clinical suspicion of late-onset neonatal sepsis (LONS) as an initial clinical test case.
3	Innovate (i.e., construct a solution idea).	Create the Artemis big data analytics platform. Create the LONS algorithm using the Artemis platform.
4	Demonstrate that the solution works.	Acquire data from neonatal infants in the NICU, The Hospital for Sick Children (Toronto) and the Women and Infants Hospital (Providence, Rhode Island, USA). Complete pilot research studies at each location for the detection of LONS in real-time as a parallel test to clinical practice to demonstrate potential (McGregor, 2011, 2013a; McGregor et al., 2013).
5	Show the theoretical connections and the research contribution of the solution concept.	Contributions to computer science in the areas of event stream processing through the deployment and commercialization of IBM's InfoSphere Streams software by IBM as a result of McGregor's First of a Kind collaboration with IBM to develop and test InfoSphere Streams within the medical context (Blount, 2010). Contributions to data warehousing through the creation of the Artemis platform (McGregor, 2013a), and temporal data mining through McGregor's patented Service-Based Temporal Data Mining framework (McGregor, 2009). Contributions to health informatics in the area of clinical decision support. Contributions to medicine in the area of pathophysiology indicators in physiological data for LONs.
6	Examine the scope of applicability of the solution.	This systemic platform is capable of performing complex analytics on physiological data within and outside the healthcare facility.

The initial practically relevant problem led to disciplinary innovation through the construction of the Artemis online software platform through a strategic partnership between researchers at the University of Ontario Institute of Technology and IBM Research. The Artemis platform is shown in Figure 1.

The development of the Artemis platform further led to disciplinary innovation in the creation of initial features within physiological data that may be predictive for the earlier onset detection of late-onset neonatal sepsis (LONS) by a neonatologist based at the Hospital for Sick Children, Toronto (McGregor et al., 2013).

Multidisciplinary research followed these two disciplinary innovation phases with the translation of the initial physiological features thought to be predictive for the earlier onset of LONS into analytics within the online analytics component of the Artemis platform. This research was considered multidisciplinary given that the researchers from computer science and medicine worked, as defined by Rosenfield (1992), in parallel with their disciplinary-specific bases to address a common problem. The real-time analytics determined whether features existed within individual physiological data and created a score based on how many features were evident (Blount et al., 2010; McGregor et al., 2013).

Using Constructive Research to Structure the Path to Transdisciplinary Innovation and Its Application for Precision Public Health with Big Data Analytics *Carolyn McGregor AM*

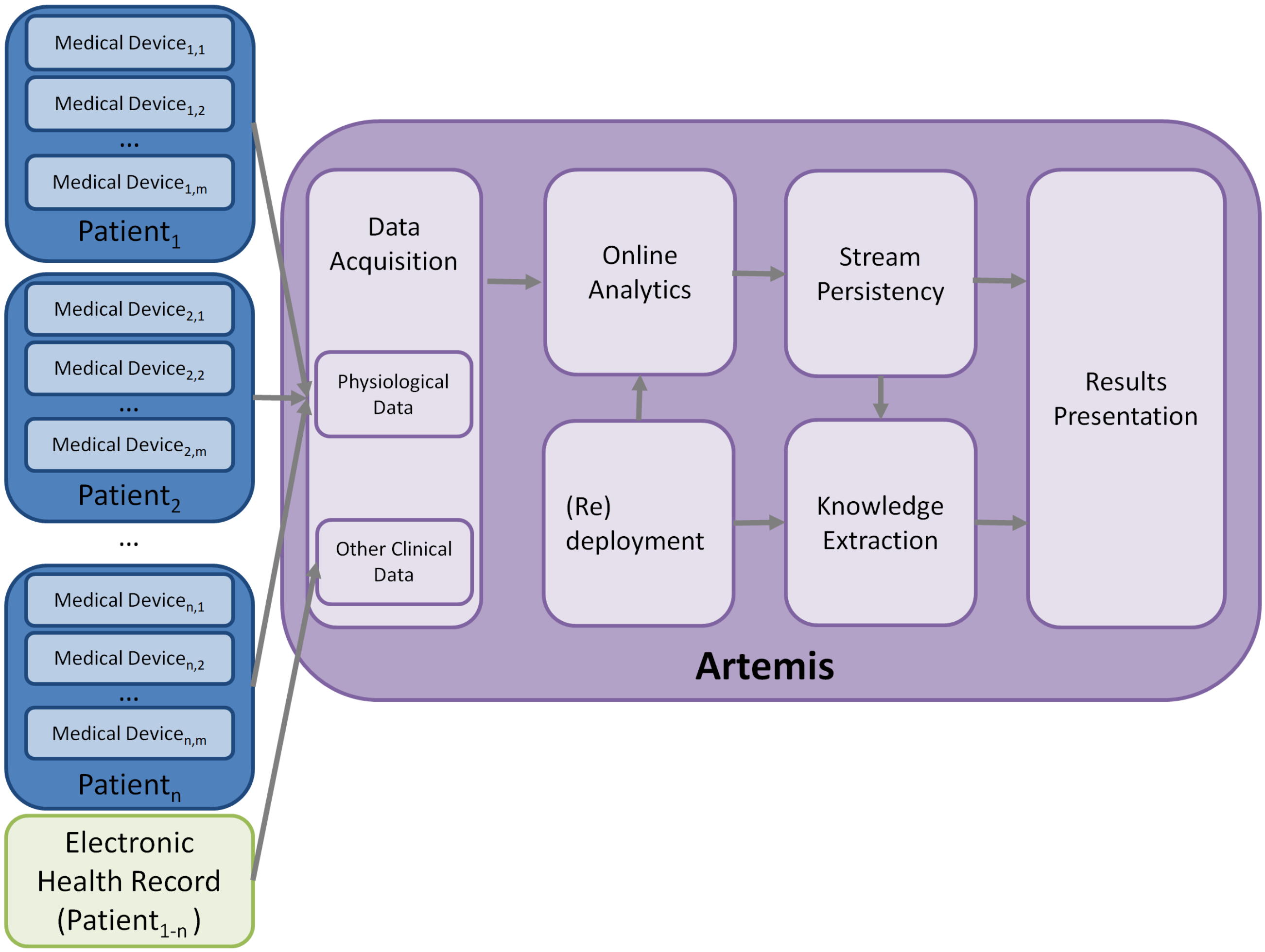

Figure 1. The Artemis platform (modified from McGregor, 2013a)

Multidisciplinary research evolved to interdisciplinary research as the technical and clinical teams learned more about the other domain. Interdisciplinarity consists of researchers working jointly but still from a disciplinary-specific basis to address a common problem (Rosenfield, 1992). This process led to an interdisciplinary research study to perform data mining and knowledge discovery for previously unknown new physiological features that were highly correlative with LONS (McGregor et al., 2012). Specifically, the discovery that the interplay between heart rate variability (HRV) and respiration variability (RRV) features as a means to remove false positives in sepsis detection that occur when HRV alone is used.

The final phase of the constructive research that created the Artemis platform led to reflection on the broader scope of applicability of the functionality of the Artemis platform for the real-time assessment of physiological data. Presentation of the Artemis platform in public and academic contexts, and interaction with professions from other domains, ultimately resulted in the application of the principles of Artemis to two distinctly different domains namely: 1) tactical operator resilience assessment and development and 2) space medicine for adaption assessment and wellness in space.

Beyond Critical Care: Big Data Analytics in Tactical Officer Resilience Assessment and Development

Tactical officers are highly trained paramilitary responders whose role is to tackle significant life-threatening situations that are outside the capabilities of front-line police officers (McGregor & Bonnis, 2017). The mental and physical stress on the body during tactical activities is intense. The rise in sympathetic nervous system activity leads quickly to a dramatic rise in heart rate during tactical combat activity, which is followed by further heart rate increases and respiration increases as combat continues (Grossman & Siddle, 2000). Tactical officers train regularly because skills such as precision weapon firing and tactical operations are perishable. However, frameworks to measure physiological response metrics for mental and physical reaction to tactical training as a means to assess skills competency and resilience remain a challenge (McGregor et al., 2015). Virtual-reality-driven training activities for tactical officers are increasingly being used for standardized training scenarios because they are a safe and cost-effective way to promote resilience training by allowing trainees to learn techniques for resilience from various stressors. McGregor, Bonnis, and Stanfield (2017) saw significant potential to explore new approaches for precision training of tactical operators through physiological monitoring that leveraged the advanced heart rate and breathing analytics within Artemis that was synchronized and integrated with training that is provisioned through a serious first-person shooter game that uses virtual reality.

A second constructive research project commenced within the context of tactical officer training, specifically for the assessment and development of resilience to create the Athena platform, which is named after the Greek goddess of warfare and wisdom. Table 2 presents a summary of the constructive research phases in this second project.

The initial practically relevant problem led to disciplinary innovation through the construction of the Athena platform as an extension to the Artemis platform. Athena enabled the integration of physiological data together with a real-time stream of gameplay information from the first person shooter game, the ARAIG Haptic garment, and ArmA 3. The Athena platform is shown in Figure 2.

The platform further led to disciplinary innovation in tactical training through the creation of training scenarios for clearing buildings, which included a structured approach to the inclusion of a range of stressors such as engaging with the enemy and seeing a team member injured.

Table 2. Phases of constructive research undertaken in the creation of the Athena platform

Phase	Constructive Research	Athena Constructive Research
1	Find a practically relevant problem that also has research potential.	How can we provide a new approach for the assessment of physiological data during tactical operator training to create new approaches for the assessment of resilience and the impact of stressors?
2	Obtain a general and comprehensive understanding of the topic.	Disciplinary understanding of current state of research for resilience assessment and physiological behaviours when under stress.
3	Innovate (i.e., construct a solution idea).	Create Athena big data analytics platform as an extension to the Artemis platform to enable the inclusion of additional streams of data from a virtual reality game. Create resilience assessment algorithms using the Athena platform.
4	Demonstrate that the solution works.	Perform an initial pilot study with Tactical Operators using ArmA 3, ARAIG, and Athena.
5	Show the theoretical connections and the research contribution of the solution concept.	Structured approaches for resilience assessment and development training for tactical operators. Contributions to computer science in the areas of data warehousing to create the Athena online software platform and serious games through the creation of a building-clearing serious game for use by tactical operators that enables resilience assessment and development.
6	Examine the scope of applicability of the solution.	This systemic platform is capable of performing complex analytics on physiological data within and outside the training facility.

Using Constructive Research to Structure the Path to Transdisciplinary Innovation and Its Application for Precision Public Health with Big Data Analytics *Carolyn McGregor AM*

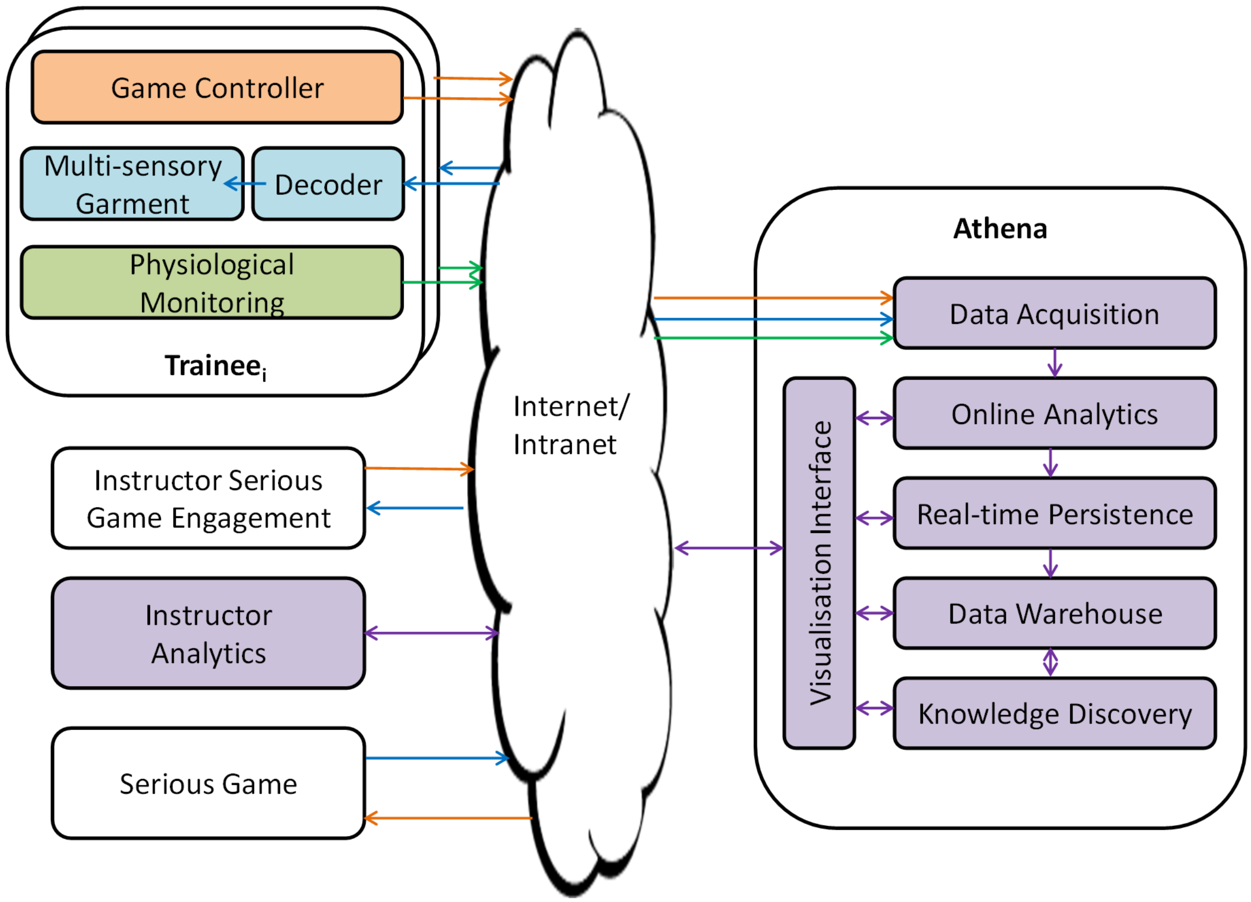

Figure 2. Integration of Athena, ArmA 3, and ARAIG (modified from McGregor et al., 2017)

Multidisciplinary research followed these two disciplinary innovation phases with the translation of the training scenario into ArmA 3. Multidisciplinary research evolved to interdisciplinary research as the technical and tactical teams learned more about the other domain. This process led to interdisciplinary research to study methods for resilience assessment and development based on structured approaches to stressor integration and new resilience analytics.

The final phase of the constructive research that created the Athena platform led to reflection on the broader scope of applicability of the functionality of the Athena platform for other first responders such as firefighters and paramedics. It also led to the realization that the resilience analytics had a broader applicability within the first responder community and those with mental health conditions such as post-traumatic stress disorder.

Beyond Earth: Big Data Analytics in Space for Adaption Assessment

A primary focus of space medicine is the estimation of risks of pathology development during long-term space flights as crew member illness or decreased performance can put the whole mission at risk (Orlov et al., 2017). Beyond the impact of weightlessness and radiation, astronauts have the potential to develop a range of medical conditions that could be developed when they are not participating in space flight. The earliest and accurate detection of the potential onset of these conditions through predictive diagnostics is of significant importance, particularly when the missions involve significant time intervals of days or weeks, where contact with mission control is not possible (McGregor, 2013b). A mathematical model of human functional states utilizing heart rate variability (HRV) analysis has been the subject of prior Russian research in space medicine (Baevsky et al., 2011). However, that research was limited to the determination of a 24-hourly human functional state score derived from averaging the functional states for each 5-minute window in a 24-hour period, resulting in significant data loss. In addition, data collection was a separate process from data analysis, with data collection occurring on the spacecraft, most recently the International Space Station. Using that approach, data is transported or transmitted to Earth for retrospective analysis after completion of the mission.

Therefore, a third constructive research project commenced within the context of space medicine and specifically for the assessment of adaption and response to the stress of space flight to create the Artemis in Space platform. A summary of the constructive research phases undertaken in this third project is presented in Table 3.

This research built on disciplinary innovation in functional state and wellness assessment during space flight. Multi-disciplinary research involved the translation of the function state algorithm into a stream processing algorithm to run in real-time within the Artemis in Space platform (Orlov et al., 2017).

Multi-disciplinary research evolved to interdisciplinary research as the technical and space medicine teams learned more about the other domain. This led to an interdisciplinary research study to methods for adaption assessment.

Again, the final phase of the constructive research led to reflection on the broader scope of applicability of the wellness approach and the realization that the wellness analytics had a broader applicability for providing health analytics in the broader community.

Table 3. Phases of constructive research undertaken in the creation of the Artemis in Space platform

Phase	Constructive Research	Artemis Constructive Research
1	Find a practically relevant problem that also has research potential.	How can we provide new approaches for the assessment of physiological data during space flight and analogue isolation to create new approaches for the assessment of adaption?
2	Obtain a general and comprehensive understanding of the topic.	Disciplinary understanding of current state of research for space adaption and physiology in space. Disciplinary understanding of current approaches for the analysis of space physiology
3	Innovate (i.e., construct a solution idea).	Create Artemis in Space big data analytics platform as an extension to the Artemis platform that enables analysis of adaption. Re-engineer functional state mathematical model to create adaption assessment algorithms using the Artemis in Space platform.
4	Demonstrate that the solution works.	Perform an initial pilot study with cosmonauts completing isolation experiment in Mars 500 facility.
5	Show the theoretical connections and the research contribution of the solution concept.	Medical contributions for new approaches to adaption and wellness assessment resulting in theoretical contributions to the function of health monitoring in space. Computer science contributions for real-time health monitoring in space resulting in theoretical contributions for analytics platforms that enable autonomous health monitoring.
6	Examine the scope of applicability of the solution.	This systemic platform is capable of performing complex analytics on physiological data within the spacecraft and outside it through the transmission of data to mission control.

Using Constructive Research to Structure the Path to Transdisciplinary Innovation and Its Application for Precision Public Health with Big Data Analytics *Carolyn McGregor AM*

The Emergence of Transdisciplinary Research and Innovation for Precision Public Health with Big Data Analytics

Drawing on step 6 of the constructive research methodology to *structure a path* for the purposeful synthesis across these three separate research initiatives anchored in similar big data analytics platforms has resulted in a broader transdisciplinary research and innovation collaboration to emerge with the socially relevant issue of precision public health as the focus. Specifically, assessing the scope of applicability enabled cross-pollination between the projects for a broader health and wellness goal that draws on the knowledge gained from all projects. This partnership has been further enabled through a strategic partnership with a fourth sector: public health with the Department of Health in Western Australia. The structured path of synthesis resulted in a collaboration that transcends beyond and integrates disciplinary paradigms across computer science, critical care medicine, aerospace, tactical operations, and public health. New research and innovation projects are now emerging to link abstract and case-specific knowledge such as the concepts of health, stressors, resilience, and adaption in a broader goal of precision public health assessment of wellness to emerge. This transdisciplinary team is now proposing new action research projects to use the assessment of stressors, resilience, and adaption through big data analytics on physiological response with environmental information as an ongoing approach to proactively assess wellness within several diverse communities including, but not limited to, preterm infants, first responders, and astronauts. This work is being progressed with a new collaboration with the Western Australian Department of Health, who are international leaders in the area of precision public health for policy-driven proof-of-concept projects.

Conclusion

This research presents a method that enables research and innovation projects to progress from disciplinary innovation to multi-disciplinary innovation, which can then evolve to interdisciplinary innovation with deeper cross-domain understanding. The final stage of the constructive research process enables a structured path for a greater transdisciplinary goal to emerge.

This method was demonstrated through a set of big data analytics research projects involving diverse disciplines such as computer science, critical care medicine, aerospace, tactical operations, and public health that result in new approaches for transdisciplinary innovation in precision public health. This method enables a structured path to elevate to transdisciplinary collaboration and can then be followed by further action based transdisciplinary research projects involving this diverse team.

About the Author

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Using Constructive Research to Structure the Path to Transdisciplinary Innovation and Its Application for Precision Public Health with Big Data Analytics *Carolyn McGregor AM*

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