Title
Convergence Science Arrives: How Does It Relate to Psychiatry?

Journal
Academic Psychiatry, 41(1)

ISSN
1042-9670

Authors
Eyre, Harris A
Lavretsky, Helen
Forbes, Malcolm
et al.

Publication Date
2017-02-01

DOI
10.1007/s40596-016-0496-0

Peer reviewed

Acad Psychiatry
DOI 10.1007/s40596-016-0496-0

IN DEPTH ARTICLE: COMMENTARY

Convergence Science Arrives: How Does It Relate to Psychiatry?

Harris A. Eyre[1] · Helen Lavretsky[2] · Malcolm Forbes[3] · Cyrus Raji[4] · Gary Small[2] · Patrick McGorry[5] · Bernhard T. Baune[1] · Charles Reynolds III[6]

Received: 28 February 2015 / Accepted: 25 January 2016

Convergence (from the Latin *convergere*, to "incline together") encompasses the juncture between diverse industries, cultures, departments, and disciplines. It is the node where traditional concepts meld, intersect, clash, and cross-pollinate. Convergence is the point from which novel insights arise, which has been termed the Medici Effect, for its role in catalyzing the Renaissance [1].

Convergence science was recently defined and promoted in two large reports [2, 3]. It was defined as "an approach to problem solving that cuts across disciplinary boundaries. It integrates knowledge, tools, and thought strategies from various fields for tackling challenges that exist at the interfaces of multiple fields" ([2], p. 13). In the context of medical science, convergence involves integration of computer science, physics, mathematics, engineering, medicine, the arts, chemistry, and biology; synergy between government, academia, and industry is also vital. Convergence, or transdisciplinary science, is suggested to surpass interdisciplinary and multidisciplinary science via a more comprehensive integration. After single disciplinary approaches, multi-disciplinarity juxtaposes two or more disciplines focused on a question, problem, topic, or theme. The disciplines remain distinct, and existing knowledge is not questioned. Interdisciplinarity involves more comprehensive integration, again, whereby a blending of diverse perspectives offers more than the sum of the parts. Transdisciplinarity offers an even more comprehensive intellectual and social integration of paradigms, systems, theories, disciplines with problem-oriented research, and development. Convergence is uniquely characterized by the creation of these novel conceptualizations and methodologic approaches. Convergence is also unique because it explores opportunities at the interface of scientific disciplines, but it is not the only way to advance science [2]. Convergence aims to foster mutual learning, innovative collaborations, and a transdisciplinary language and knowledge integration to solve specific problems [2]. A diagrammatic overview of the differences between uni-, multi-, inter-, and transdisciplinary sciences are outlined in Fig. 1. Importantly, there are still ongoing debates around the differentiation between inter- and transdisciplinary approaches to science and medical innovation [4].

Modern psychiatric research problems are characterized by their complexity, multi-systemic nature, and broad societal impact, hence making them poorly suited to siloed approaches of thinking and innovation. Psychiatry involves the integration of insights from the mind, the brain, and behavior. The promotion of convergent approaches to psychiatry is thus important for improving mental health. Convergence psychiatry is a novel term and refers to the expressed embedding of convergence science into the clinical psychiatric context, which may occur by engaging clinicians, researchers, and

✉ Harris A. Eyre
Harris.eyre@gmail.com

[1] University of Adelaide, Adelaide, South Australia, Australia

[2] Semel Institute for Neuroscience and Human Behavior, UCLA, Los Angeles, California, USA

[3] James Cook University, Townsville, Queensland, Australia

[4] UCLA, Los Angeles, California, USA

[5] University of Melbourne, Melbourne, Victoria, Australia

[6] University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, USA

Published online: 10 March 2016

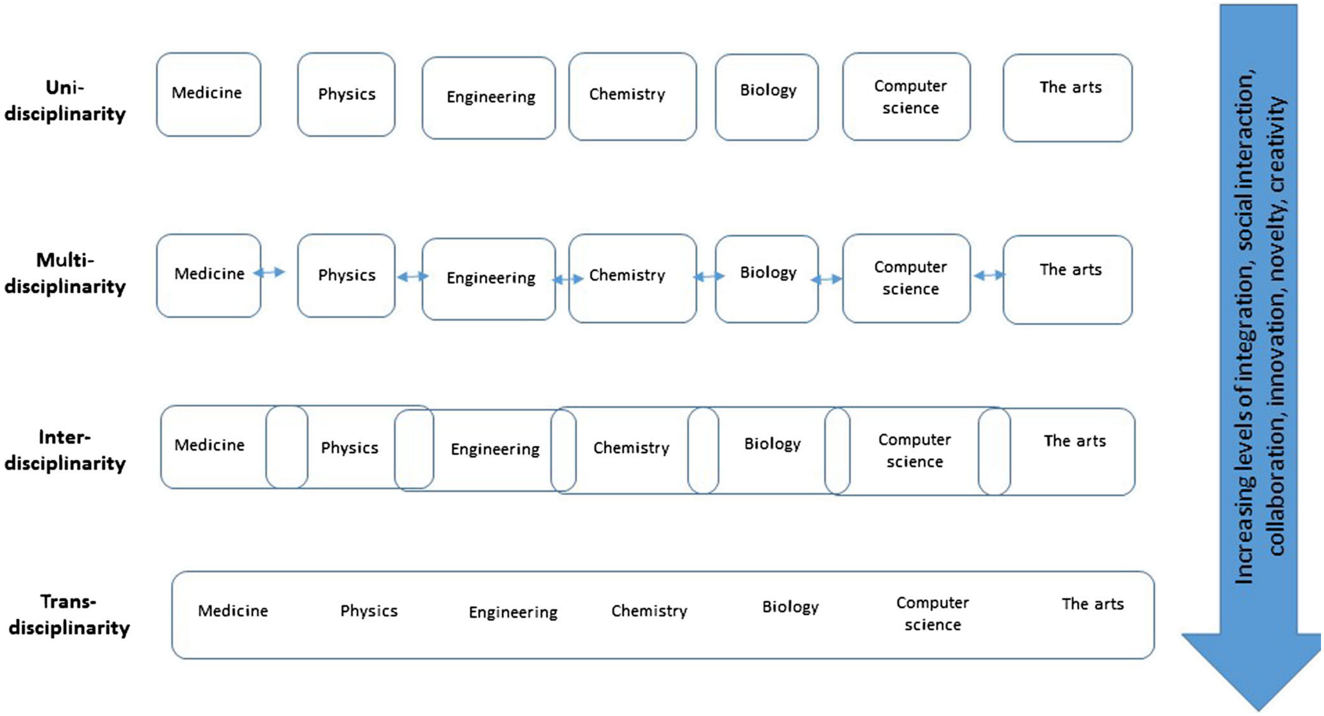

Fig. 1 Diagrammatic representation of uni-, multi-, inter-, and transdisciplinary science. This figure outlines the increasing levels of integration, social interaction, collaboration, innovation, and creativity arising from the various types of approaches to science. Transdisciplinary or convergence science is unique given it is the most comprehensive integration of the disciplines, and generates unforeseen and highly unique theories, knowledges, and mindsets

industry more closely together for teamwork or by upskilling clinicians in convergence knowledge, processes, and mindsets. In this paper, we outline why convergence science approaches should be strengthened in psychiatry.

Insights From Convergence Science in Medicine

A number of convergence-focused research institutes have recently been developed. These provide a framework for enhancing research, clinical innovation, and workforce development toward convergence in medicine and psychiatry. One novel example is the Frances Crick Institute in London [5], which opened in 2015. The Crick's internal structure is not arranged along disciplinary lines; instead, bottom-up development is encouraged of interest groups that bring together researchers from across the organization to share insights and plan activities in areas of common scientific interest. The building was constructed to encourage mixing among all scientific staff, with break-out spaces, transparent partitions, and open spaces. Postgraduate students and researchers are intentionally drawn from a diverse array of scientific and industry fields. In a recent editorial [6] regarding the Frances Crick Institute, Sir Paul Nurse, director and executive director, was requested to justify concerns surrounding the role of the institute in the process of brain drain from less revered organizations, as well as the role of the flagship institute in developing a two-tier perception of research institutes. He was also asked to respond to perceived lack of strategic direction of the institute. Nurse outlined that detailed strategic plans for convergence-focused institutes can become redundant quickly, given the pace and unpredictability of convergence science, hence supporting a strategy focused on values, aspirations, and modes of delivery.

Singularity University in San Francisco [7] is another convergence-focused organization. The goal is to provide educational programs, partnerships, and a startup accelerator to help individuals, businesses, institutions, investors, non-governmental organizations, and governments to understand and utilize innovative technologies, primarily computing-based technologies. As of 2015, 8689 individuals have been educated through an array of early-, mid-, and late-career programs. Ninety-three countries are represented through education and technology-focused 109 impact initiatives which have been developed.

Stanford University's BioX [8] is a convergence-focused organization that draws faculty and students from all seven schools across the university. Bio-X provides critical resources—seed grants, graduate fellowships, and venture funds—to drive early-stage research and educate a new generation of interdisciplinary scientist-leaders. BioX provides interdisciplinary initiatives program grants to teams of faculty partnering across fields, averaging $200,000 over 2 years. There have been considerable successes from this organization, with 30 patient filings from numerous startup companies and 500 interdisciplinary teams from 60 departments; projects have developed into federally funded labs.

Recent advances in genomic and proteomic analytics, computational science, and nanotechnology have researchers and clinicians exploring the utility of the convergence science model for molecular diagnosis and individualized therapies in oncology [9]. The new journal *Convergent Science Physical Oncology* [10] was launched in 2015 with the aim of integrating physical sciences with cancer biology and clinical care. The Center for Strategic Scientific Initiatives [11], under the auspices of the National Cancer Institute (NCI), is now promoting convergent approaches to cancer innovation. Their mission is to "create and implement exploratory programs focused on the development and integration of advanced technologies, transdisciplinary approaches, infrastructures, and standards to accelerate the creation of publically available, broadly accessible, multi-dimensional data, knowledge, and tools to empower the entire cancer research continuum for patient benefits" [11]. The NCI's Division of Cancer Biology has developed a Physical Sciences in Oncology Initiative [12] to establish research projects that bring together cancer biologists and oncologists with scientists from the fields of physics, mathematics, chemistry, and engineering to address major questions and barriers in cancer research. In 2009, the Physical Sciences–Oncology Centers (PS-OCs) Program was launched, a network of 12 centers investigating complex and challenging questions in cancer research from a physical sciences perspective. Examples of thought-provoking projects arising from these PS-OCs include engineering white blood cells to kill off tumor cells found in the blood [13], using radio waves to increase the efficiency of chemotherapy [14], and using game theory concepts to model how resistance to chemotherapy develops in tumor cells [15]. A private clinical care company is now providing convergence-based oncology care in the USA [16], but data are required to understand the patient care outcomes.

Importance of Convergence Science in Psychiatry

Arguably, if oncology is so complex to require a convergent approach, then the study of psychiatry (mind, brain, and behavior) is complexity on a whole different level. Therefore, promoting the importation of convergence science into psychiatry and allied mental health disciplines is important for a number of reasons. It could further assist the psychiatric profession in developing research and clinical and public health innovations that can more optimally tackle complex challenges. These complex challenges include rising rates of chronic physical and mental disorders resulting from population aging and suboptimal health behaviors, inefficient health systems, low rates of treatment success with current approaches, and the mental health effects of rapid urbanization and social inequality. These problems share diverse and multifactorial etiologies, manifestations, and consequences extending across often unconnected sectors. Convergence science insights can enhance the engagement of the psychiatric profession with non-clinical innovations that include making discoveries in molecular biology, advancing neuroimaging, reducing costs of genomic and proteomic profiling, raising computing power, increasing uptake of electronic health records, increasing uptake of Internet and smartphone use, and improving understanding of the social determinants of mental health.

Examples of Convergent Approaches to Psychiatry

We present here examples of convergent approaches to research, clinical practice, and public health. These can be considered in terms of specific studies, fields of research, initiatives supporting research, public health programs, and actual examples of convergence in clinical care.

Convergent Fields of Psychiatric Research

There have been calls for many years to innovate psychiatric research and clinical care through translational psychiatry [17]. Translational skills are believed to be important given that therapies based on the old monoamine model still form the basis of current depression treatment and given the significant gap between the expansion of neuroscience knowledge and translation into novel treatments [17]. The working steps of translational psychiatry, as outlined by Licinio [17], include, in a one-way direction: (T0) discovery (via pre-clinical, clinical and epidemiological science); (T1) bench to bedside; (T2) bedside to clinical applications (clinical trials); (T3) translation to policy and health care guidelines; (T4) assessment of health policy and usage; and (T5) global health applications. Many areas of medical research contribute to this area, including molecular biology, genetics, pharmacology, neuroimaging, epidemiology, and immunology.

While there are similarities between translational psychiatry and convergence psychiatry in the focus of poly-discipline research, there are also differences. Convergence psychiatry expressly involves transdisciplinary considerations, whereas translational psychiatry traditionally adheres to multi- and inter-disciplinary science approaches. Convergence psychiatry includes fields such as 3D printing, socially assistive robotics, and artificial intelligence, which may not fall under the translational psychiatry rubric that traditionally engages into the more biological fields. Translational psychiatry also aims to take a structured, one-way approach to translation, whereas convergence psychiatry understands but is not fixed to this approach.

Behavioral neuroeconomics is a field with increasing relevance in psychiatry that aims to provide a neural foundation for economics models of health-related choices and decision making [18]. Behavioral neuroeconomics involves problems at the intersection of psychology, neuroscience, and economics. Exemplifying the relevance of this field to psychiatry is a recent study [18] exploring the relationship between adolescent preference for immediate reward and neural activation in brain regions mediating impulsive/habitual behavioral choices as well as reflective/executive behavioral choices. This was a model of understanding adolescent substance use. Results support relations between competing executive and reward valuation neural networks and temporal decision making. This is now a biomarker for treatment and prevention of substance use.

Another convergent field of study relevant to psychiatry is geroscience, an interdisciplinary field that aims to understand the relationship between the mechanisms of aging and age-related diseases and then slow or halt the process of aging and hence disease development [19]. In this field, researchers in a variety of disciplines may work together, sharing data and paradigms. Geroscience is supported by the Trans-NIH GeroScience Interest Group, with some 20 NIH institutes and centers participating. The group was founded by program scientists from NIA and other institutes to find ways to collaborate and coordinate. One example of geroscience in early-stage research is rapamycin, a Federal Drug Administration (FDA)-approved compound. Rapamycin was the first pharmacological agent shown to extend maximal lifespan in both genders in a mammalian species. Rapamycin is an inhibitor of mammalian target of rapamycin (mTOR), a kinase at a key signaling node that integrates information regarding extracellular growth factor stimulation, nutrient availability, and energy supplies [20]. Translational studies that assess rapamycin's effects on human aging and age-related disease are thought to be within reach and have actually been initiated at some sites [21].

Examples of Convergent Research Initiatives

The Brain Initiative

The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) [22] is an example of convergence neuroscience. In 2013, the US Government launched this initiative to "accelerate the development and application of new technologies that will enable researchers to produce dynamic pictures of the brain that show how individual brain cells and complex neural circuits interact at the speed of thought" [22]. One of the expressed themes of action for the BRAIN initiative is to "cross boundaries in interdisciplinary collaborations" [22]. The rationale for this initiative is that no single research discipline will solve the brain's mysteries. Emphasizing the cross-disciplinary nature of this endeavor, an advisory board will be created for the BRAIN initiative with experts from diverse fields—neuroscience, the clinical sciences, the physical and quantitative sciences, and humanities [22]. The BRAIN initiative members suggest "the most exciting approaches to discovery in neuroscience are likely to come from innovative bridging of fields, linking experiment to theory, biology to engineering, tool development to experimental application, human neuroscience to non-human models" [22]. The initiative aims to "establish platforms for sharing data," which require engineering, biomathematical, and infrastructure investments [22]. Public, integrated repositories for datasets and data analysis tools, with an emphasis on easy data access and effective central maintenance, will be devised. The BRAIN initiative has existing cross-over with the humanities in its aim to "consider ethical implications of neuroscience research" [22]. BRAIN initiative research may raise important issues about neural enhancement, data privacy, and appropriate use of brain data in law, education, and business [22]. Some of the early outcomes of the BRAIN initiative are promising and include Drop-seq, a high throughput technique for single cell analysis based on genetic coding [23]. Another is the development of Designer Receptor Exclusively Activated by Designer Drugs (DREADD) technology, which targets kapp-opioid receptors and thereby can allow for bidirectional control of neuronal circuits [24].

Research Domain Criteria Project

The National Institute of Mental Health-funded Research Domain Criteria (RDoC) project [25] emulates the aspirations of convergence medicine in psychiatry. RDoC is an experimental approach to the classification of mental disorders that incorporates multiple dimensions: behavior, thought patterns, neurobiological measures, and genetics [25]. An immediate aim of the project to develop a diagnostic system that departs from reliance on phenomenology and embraces a matrix spanning genetic, molecular, cellular, brain circuit individual, family environment, and social levels. It thus implicitly demands a transdisciplinary convergent approach. RDoC has a major objective of curating psychiatric neuroscience research into an organizing matrix to allow a neuroscience-based research and hence understanding of symptomatology (e.g., negative valence systems and cognitive systems) [26]. Already, the scientific community has embraced the opportunity to think beyond current classifiers, with nearly 1000 papers addressing various aspects of RDoC over 2014 [27]. As an example of an RDoC-inspired research study, Karalunas et al. [28] were able to refine subtyping of childhood attention-deficit/hyperactivity disorder by using biologically based behavioral dimensions (e.g., temperament), a novel classification algorithm (e.g., community detection analysis), and multiple external validators (e.g., resting state functional magnetic resonance imaging and cardiac measures of respiratory sinus arrhythmia and pre-ejection period).

Examples of Convergent Public Mental Health Projects

Given the huge, unaddressed global burden of psychiatric disorders and the limited effectiveness of available treatments [29], innovative management practices and solutions are required. Promising developments in the field of global mental health assist in addressing the burden of worldwide disease [30]. The global mental health movement has positioned itself well and captured the interest of a wide range of stakeholders, from consumer and civil society groups, to national policymakers, to international donors and development agencies [30]. In mid 2013, the World Health Assembly adapted the World Health Organization Comprehensive Mental Health Action Plan [31], recognizing mental health as a global priority and pledging action. As outlined by Patel and colleagues [32], mental health is now discussed at the highest level policy forums devoted to global health and development, such as the recent World Innovation Summit for Health (WISH) and the World Economic Forum.

On the scientific side of the global mental health movement, innovations are being developed that successfully address the health and social needs of people with mental disorders in poorly resourced settings [32]. A key example is psychosocial treatment delivered via mobile health (mHealth), which involves the practice of medicine supported by mobile devices and has the benefit of reach, scalability, affordability, convenience, flexibility, and facilitation by a non-professional workforce. An mHealth approach for mental health is Massive Open Online Interventions (MOOI), a term recently defined by Munoz et al. [33] that describes interventions which are scientifically validated and available online to unlimited numbers of consumers. MOOIs are increasingly relevant, given rising rates of Internet availability around the work with now over 3 billion Internet users in total, with two-thirds from the developing world [34]. One example of a MOOI comes from a study of smoking cessation [33]. A free, multi-factorial online program for smoking cessation was available in Spanish and English for 30 months, free of charge, and this lead to 292,978 individuals from 168 countries visiting the site. A total of 7507 participants were screened for eligibility, consented, and underwent baseline surveying. Quit rates were 50.3 % at 12 months. These interesting findings open opportunities and challenges for global health projects in other mental health disorders such as depression. It should be noted with mHealth concerns surround questions over acceptability to consumers, quality of interaction and potential for unsupervised and counterproductive therapy.

Convergent Research Studies in Psychiatry

As a first step, convergence may simply be combining the current tools for diagnosis. The neurobiological mechanisms of psychiatric disorders are complex and often involve interplay of changes in brain structure, function, neurochemistry, and neuropathology. A study by Clark et al. [35] explored the risk of individual progression from clinical high risk for psychosis to first episode psychosis with multi-modal diagnostics from clinical interview, structural magnetic resonance imaging, neuropsychological testing, and electroencephalography. Data from published studies were explored, and predictive models were used based on the odds ratio form of Bayes' rule. In brief, several modalities of investigation were seen to be necessary to arrive at clinically meaningful risk predictions for conversion. This was particularly true for a group of patients whose initial test results (e.g., clinical and cognitive) were equivocal. For such individuals, at least four tests were required to determine the actual risk profile. This study outlines the enhancement of mental health diagnostics through integration of data from various, often siloed fields.

A recent study by Papakostas et al. [36] explored the value of multi-system, serum-based testing for major depressive disorder (MDD) versus non-depressed health controls. The investigators took a wide array of biomarkers from various biological systems (determined via earlier data-driven research) systems seldom considered together in diagnostics, such as alpha1 antitrypsin, apolipoprotein CIII, brain-derived neurotrophic factor, cortisol, epidermal growth factor, myeloperoxidase, prolactin, resistin, and soluble tumor necrosis factor alpha receptor type II. The results from this pilot study yielded a sensitivity and specificity of 91.7 and 81.3 %, respectively, in differentiating between the depressed and non-depressed groups. This study highlights the value of using "bottom-up" data-driven approaches to inform diagnostic strategies which incorporate a number of biological systems.

A study by Ayalew et al. [37] used a translational convergent functional genomics approach to identifying genes associated with schizophrenia, which involved gene-level integration of genome-wide association study data with other genetic and gene expression studies in humans and rodent models. The top candidate genes from humans and rodents were then taken and used to generate a genetic risk prediction score to aid schizophrenia diagnostics. In three independent cohorts, this risk prediction score was useful in predicting the age of onset of schizophrenia. This model highlights the utility of translational and convergent methods for understanding the molecular signature of complex mind/brain disorders like schizophrenia.

While all of these examples draw from multiple data sources, the ultimate promise of convergence is the integration of biological, psychological, socio-cultural, and environmental data into a more comprehensive, individualized portrayal of diagnosis (so called precision medicine [28]).

Examples of Convergence in Psychiatric Care

Pharmacogenomics

Pharmacogenomic technologies are an example of a convergent innovation that may be applied to clinical care [38]. A recent randomized controlled trial (RCT) compared the depression treatment outcome prediction of a combinatorial gene approach versus treatment as usual (TAU) [39]. In this study, the combinatorial genes included four cytochrome *P*450 (CYP) enzymes (*CYP2D6*, *CYP2C19*, *CYP2C9*, and *CYP1A2*), the serotonin transporter (*SLC6A4*), and serotonin 2A receptor (*HTR2A*). This technology categorizes each of 26 psychotropic medications within a green, yellow, or red "bin" based on the relationship of each medication to a subject's pharmacokinetic and pharmacodynamic combinatorial gene variant profile. Depressed adult outpatients were randomized to a TAU ($n=25$) arm or a pharmacogenomic-informed ($n=26$) arm. Depression severity was measured by blinded study raters at baseline and then 4, 6, and 10 weeks post. Mean percent improvement in depressive symptoms on the Hamilton Depression Rating Scale appeared to be higher for the combinatorial gene group over TAU (30.8 vs 20.7 %). These improvements, if confirmed in an adequately powered trial, may support pharmacogenomically informed strategies for both maximizing efficacy and reducing toxicity. Retrospective pharmacogenomic testing based on the above combinatorial approach has been shown to identify past inappropriate medication selection, which led to increased healthcare utilization and cost [40].

Preventive Neuroradiology

The main rationale of preventive neuroradiology [41] is the application of multi-modal brain imaging toward early detection of brain disease (prior to frank, syndromal expression) and subsequent preventive actions through identification of modifiable risk factors. An example of this is in the area of age-related cognitive decline, mild cognitive impairment, and dementia, with potentially modifiable risk factors such as obesity, diet, sleep, hypertension, diabetes, depression, supplementation, smoking, and physical activity. When operationalizing preventive neuroradiology in a clinical setting, imaging doctors act as actionable information consultants to referring physicians and their patients with the aim of delivering the added value of quantitative neuroimaging. Accurate, rapid, automated quantitation of brain volume is an integral part of this area and must be further developed.

Socially Assistive Robotics

The field of socially assistive robotics (SAR) in mental health, whereby robots assist patients through social interactions (i.e., companionship, therapeutic partner and/or coach), is receiving greater attention, particularly as computing power grows and artificial intelligence systems become more sophisticated, ubiquitous, and useful. A recent review [42] has outlined potential benefits of SAR (i.e., proving therapy and monitoring where there are few mental health providers and reinforcing human-led therapy), as well as potential downsides (i.e., poor quality user interface leading to frustration and cost considerations). This review highlights the potential for SARs to support as emotional and physical companions, therapeutic play patterns, as well as coaches. There are some preliminary studies across a spectrum of disorders (e.g., dementia, depression, autism) and age ranges. It is expected this field will burgeon as technological advances continue to accelerate. Care must be taken to advance this field with quality research and ethical considerations.

Integrated Clinical Operating Systems

To operationalize a convergent clinical framework will require effective direction and utilization of the large amounts of data generated [43]. The role of digital clinical operating systems is therefore critical for allowing effective patient care, as well as ongoing research. These clinical operating systems house data from clinical encounters, imaging, pathology, personal medical devices, wearables, and finance [43]. Analytics methods include the use of mathematical and algorithmic-based processing of data resources, as well as the use of techniques such as text mining, natural language processing, and visual analytics to generate descriptive, predictive and prescriptive models to analyze and derive insight from data [44]. Big Data analytics such as machine learning have been utilized predictive risk assessment, clinical decision support, home health monitoring, finance, and resource allocation [43]. Data security and privacy is clearly key in the Data Age.

Strengths of Convergence Psychiatry

Psychiatrists, non-medical convergence researchers and innovators, health systems, research institutes, private enterprises, and the community stand to benefit from greater uptake of convergence psychiatry. Benefits for psychiatrists may include enhanced job satisfaction resulting from creativity and an enhanced ability to effect innovation in clinical care. Non-medical convergence researchers and innovators, via collaboration with clinicians, will have a greater access to and hence understanding of clinical care. The community will benefit from novel innovations aimed to improve societal health and outcomes.

Drawbacks of Convergence Psychiatry

Uptake of convergence psychiatry is not without downsides. Transdisciplinary approaches require further validation by means of successful innovations and clearer distinction from interdisciplinary approaches [4]. For all involved in convergence psychiatry, there is the daunting task of engaging in a multitude of fields outside of one's traditional training; hence, a huge knowledge and skill acquisition task is needed. However, this provides a rationale for educational reforms, described in the following section. For health systems, research institutes, and private enterprises, there will be complexity with sharing of intellectual property and economic outcomes from convergent innovations. Convergence psychiatry organizations need clear measures to monitor the "success" of convergence and to track intra- and inter-institutional convergence. Researchers in the USA are exploring mechanisms for assessing the quality and productivity of transdisciplinarity within and among medical research and innovation institutions [4]. These approaches include concepts and tools such as collaborative-readiness including *contextual–environmental conditions, intrapersonal characteristics*, and *interpersonal factors*. Collaborative products are also assessed include integration of research and training across investigators' offices, conference rooms, and laboratories. Collaborative products were also determined by cross-disciplinary qualities reflected in tangible collaborative products.

Convergence Science in Psychiatric Education

To strengthen the field of convergence psychiatry, convergent concepts should begin to be taught through educational curricula. Additional skills may include an enhanced understanding of neuroscience, 'omics (i.e., genomics, proteomics and metabolomics), big data analytics, mHealth, economics, and policy.

The enhanced teaching of convergence science is suggested by the National Research Council (NRC) report, stating "there must be a promotion of training that makes interdisciplinary connections, incorporates the science of learning and access to research opportunities, and draws on validated, evidence-based teaching methods" ([2], p. 39). A report from the Association of American Medical Colleges and the Howard Hughes Medical Institute, "Scientific Foundations for Future Physicians" [45], concur with this. New revisions to the medical school admission test (MCAT) also align with an increased focus on convergent thinking, with revisions focusing on "demonstrating core competency in key biological concepts and draw on the integration of several fields, rather than on testing specific courses or disciplines in isolation" ([2], p. 39).

As an example of engagement in undergraduate training, the NRC Report Committee commented on the convergence-rich educational environment provided by undergraduate liberal arts colleges, as well as smaller Science, Technology, Engineering, and Mathematics (STEM)-focused schools [2]. These institutions have educational models that support the goals of convergence via encouraging educators to develop methods of teaching that span multiple disciplines [2]. Smaller class sizes and smaller physical campus sizes also foster more opportunities for convergent thinking [2].

A recent editorial by leaders within the American Psychiatric Association [46] suggests that training of future psychiatrists must involve teaching a greater breadth of skills. Relevant non-clinical skills suggested include quality improvement and health system reform skills, as well as processes for performing population-based interventions. Yager [47] suggests psychiatry training and careers are likely to undergo substantial change in the future to match to projected health burdens and innovations. He postulates that future additional psychiatric specializations may revolve around information technology and executive management (e.g., combining clinical practice, administration, entrepreneurialism, and health services management). He also suggests upgrades in neuroscience learning, health economics, and organizational dynamics [47].

The Summary Research Institute in Geriatric Mental Health is a helpful model to understand convergent educational programs [48]. The Summer Research Institute, funded for 20 years by the National Institute of Mental Health (NIMH), is a national program promoting career advancement of post-residency and post-doctoral fellows and other investigators who hold promise for a research career in geriatric mental health translation, interventions, or services research. The institute meets as an annual 5-day research career development institute for a competitively selected set of trainees that provides learning opportunities via one-to-one and group mentoring. There is a focus on interdisciplinary learning and project engagement. This research education model instantiates team-based, transdisciplinary, and translational learning using a hands-on model of active learning.

The training of psychiatrists as clinical neuroscientists has recently been outlined, and indeed, there are signs to suggest a resurgence in medical students interested in psychiatric neuroscience given the need for new discoveries and promise of new research techniques [49]. Interesting educational curricula to model off include the NIMH-led, 4-day Brain Camp offered in the USA to MD-PhD students [50].

There are important questions to be debated and researched in the context of convergence psychiatry education: what training models will effectively teach convergence principles? Do current education frameworks allow for convergence principles? It is important to consider the mix of depth and breadth of knowledge across all of these disciplines.

Implications of Convergence Psychiatry

There are a number of implications for a greater engagement of convergence science in psychiatry. From a workforce perspective, greater engagement of clinical psychiatrists in non-clinical convergence activities (e.g., research, entrepreneurship) may reduce time spent in front-line service provision roles. Ethical considerations are relevant, whereby greater links and exposure of practitioners and researchers to private industry fields will increasingly expose them to potential conflicts of interest. Differing objectives and ethos of clinical-academic and industry may potentially cause conflict [51]. Researchers may be concerned with restrictions to academic freedoms and the right to publish, industry may be more focused on protection of confidential information and intellectual property, market penetration, and shareholder values [51].

In conclusion, convergence psychiatry is a novel field with potential value for the future of research, clinical care, and public health. There are now growing numbers of convergent studies, fields of research, institutes, and initiatives promoting this concept. Articulating the scope, promise, cost, and possible pitfalls of this field will help to elevate discussions on how to tackle fundamental structural challenges in our research universities, research funding, workforce policies, and partnerships. Finally, the principles of convergence science may help inform the journey from big data, to knowledge, and ultimately to wisdom through its emphasis on core values of collaboration and openness. It will increase the probability of the right use of knowledge.

Compliance with Ethical Standards

Disclosure On behalf of all the authors, the corresponding author states that there is no conflict of interest.

References

1. Johansson F. The Medici effect: Breakthrough insights at the intersection of ideas, concepts, and cultures. : Harvard Business Press; 2004.
2. NRC. Convergence: facilitating transdisciplinary integration of life sciences, physical sciences, engineering, and beyond. 2014.
3. Roco MC, Bainbridge WS, Tonn B, Whitesides G. Converging knowledge, technology and society: Beyond convergence of nano-bio-info-cognitive technologies. Dordecht, Heidelberg, New York, London: Springer; 2013.
4. Hall KL, Stokols D, Moser RP, Taylor BK, Thornquist MD, Nebeling LC, et al. The collaboration readiness of transdisciplinary research teams and centers findings from the National Cancer Institute's TREC Year-One evaluation study. Am J Prev Med. 2008;35(2 Suppl):S161–72.
5. FCI. The Francis Crick Institute. http://www.crick.ac.uk/2015 [04/09/15].
6. Nurse P. In answer to questions about the Francis Crick institute. Lancet. 2012;379(9835):2427–8.
7. SU. Singularity University. http://singularityu.org/2015 [04/09/15].
8. BIOX. Bio-X: Pioneering discoveries in benefit of human health. 2014.
9. Phan JH, Moffitt RA, Stokes TH, Liu J, Young AN, Nie S, et al. Convergence of biomarkers, bioinformatics and nanotechnology for individualized cancer treatment. Trends Biotechnol. 2009;27(6):350–8.
10. IOPScience. Convergent science physical oncology. 2015 [06/04/15]; Available from: http://iopscience.iop.org/2057-1739.
11. NCI. Center for Strategic Scientific Initiatives. National Cancer Institute2015 [04/26/15]; Available from: http://cssi.cancer.gov/
12. NCI. Physical sciences in oncology. http://physics.cancer.gov/opso/ 2015 [9/9/15].
13. Mitchell MJ, Wayne E, Rana K, Schaffer CB, King MR. TRAIL-coated leukocytes that kill cancer cells in the circulation. Proc Natl Acad Sci U S A. 2014;111(3):930–5.
14. Ware MJ, Tinger S, Colbert KL, Corr SJ, Rees P, Koshkina N, et al. Radiofrequency treatment alters cancer cell phenotype. Sci Reports. 2015;5:12083.
15. Wu A, Liao D, Tlsty TD, Sturm JC, Austin RH. Game theory in the death galaxy: interaction of cancer and stromal cells in tumour microenvironment. Interface Focus. 2014;4(4):20140028.
16. NANTHEALTH. NANTHEALTH LLC. Los Angeles 2014 [12/22/14]; Available from: http://nanthealth.com/.
17. Licinio J, Wong ML. Launching the 'war on mental illness'. Mol Psychiatry. 2014;19(1):1–5.
18. Stanger C, Elton A, Ryan SR, James GA, Budney AJ, Kilts CD. Neuroeconomics and adolescent substance abuse: individual differences in neural networks and delay discounting. J Am Acad Child Adolesc Psychiatry. 2013;52(7):747–55. e6.
19. Burch JB, Augustine AD, Frieden LA, Hadley E, Howcroft TK, Johnson R, et al. Advances in geroscience: impact on healthspan and chronic disease. J Gerontol A Biol Sci Med Sci. 2014;69 Suppl 1:S1–3.
20. Ehninger D. From genes to cognition in tuberous sclerosis: implications for mTOR inhibitor-based treatment approaches. Neuropharmacology. 2013;68:97–105.
21. Biomedicine LM. A putative antiaging drug takes a step from mice to men. Science. 2013;342(6160):789.
22. NIH. BRAIN 2025: A scientific vision. Online: NIH, 2014.
23. Macosko EZ, Basu A, Satija R, Nemesh J, Shekhar K, Goldman M, et al. Highly parallel genome-wide expression profiling of individual cells using nanoliter droplets. Cell. 2015;161(5):1202–14.
24. Vardy E, Robinson JE, Li C, Olsen RH, DiBerto JF, Giguere PM, et al. A new DREADD facilitates the multiplexed chemogenetic interrogation of behavior. Neuron. 2015;86(4):936–46.
25. Insel T, Cuthbert B, Garvey M, Heinssen R, Pine DS, Quinn K, et al. Research domain criteria (RDoC): toward a new classification framework for research on mental disorders. Am J Psychiatry. 2010;167(7):748–51.
26. NIMH. Research Domain Criteria (RDoC). http://www.nimh.nih.gov/research-priorities/rdoc/index.shtml2015 [9/9/15].
27. Insel TR, Cuthbert BN. Medicine. brain disorders? precisely. Science. 2015;348(6234):499–500.
28. Karalunas SL, Fair D, Musser ED, Aykes K, Iyer SP, Nigg JT. Subtyping attention-deficit/hyperactivity disorder using temperament dimensions: toward biologically based nosologic criteria. JAMA Psychiatry. 2014;71(9):1015–24.
29. Whiteford HA, Degenhardt L, Rehm J, Baxter AJ, Ferrari AJ, Erskine HE, et al. Global burden of disease attributable to mental and substance use disorders: findings from the Global Burden of Disease Study 2010. Lancet. 2013;382(9904):1575–86.
30. Patel V. Why mental health matters to global health. Transcult Psychiatry. 2014;51(6):777–89.
31. Saxena S, Funk M, Chisholm D. World health assembly adopts comprehensive mental health action plan 2013-2020. Lancet. 2013;381(9882):1970–1.

32. Patel V, Saxena S. Transforming lives, enhancing communities—innovations in global mental health. N Engl J Med. 2014;370(6): 498–501.
33. Munoz RF; Bunge EL; Chen K; Schueller SM; Bravin JI; Shaughnessy EA, et al. Massive open online interventions: a novel model for delivering behavioral health services worldwide. Clinical Psychological Science. 2015.
34. ITU. Yearbook of statistics: chronological time eries 2004-2013. Geneva: 2014.
35. Clark SR, Schubert KO, Baune BT. Towards indicated prevention of psychosis: using probabilistic assessments of transition risk in psychosis prodrome. J Neural Transm. 2015;122(1):155–69.
36. Papakostas GI, Shelton RC, Kinrys G, Henry ME, Bakow BR, Lipkin SH, et al. Assessment of a multi-assay, serum-based biological diagnostic test for major depressive disorder: a pilot and replication study. Mol Psychiatry. 2013;18(3):332–9.
37. Ayalew M, Le-Niculescu H, Levey DF, Jain N, Changala B, Patel SD, et al. Convergent functional genomics of schizophrenia: from comprehensive understanding to genetic risk prediction. Mol Psychiatry. 2012;17(9):887–905.
38. Altar CA; Carhart JM; Allen JD; Hall-Flavin DK; Dechairo BM; Winner JG. Clinical validity: combinatorial pharmacogenomics predicts antidepressant responses and healthcare utilizations better than single gene phenotypes. The pharmacogenomics journal. 2015.
39. Winner JG, Carhart JM, Altar CA, Allen JD, Dechairo BM. A prospective, randomized, double-blind study assessing the clinical impact of integrated pharmacogenomic testing for major depressive disorder. Discovery Med. 2013;16(89):219–27.
40. Winner J, Allen JD, Altar CA, Spahic-Mihajlovic A. Psychiatric pharmacogenomics predicts health resource utilization of outpatients with anxiety and depression. Translational Psychiatry. 2013;3:e242.
41. Raji C; Eyre HA; Wei SH; Bredesen D; Moylan S; Law M, et al. Hot topics in research: preventive neuroradiology in brain aging and cognitive decline. American Journal of Neuroradiology. 2015;In Press.
42. Rabbitt SM, Kazdin AE, Scassellati B. Integrating socially assistive robotics into mental healthcare interventions: applications and recommendations for expanded use. Clin Psychol Rev. 2015;35:35–46.
43. Simpao AF, Ahumada LM, Galvez JA, Rehman MA. A review of analytics and clinical informatics in health care. J Med Syst. 2014;38(4):45.
44. Kudyba S. Healthcare informatics: increasing efficiency and productivity. Francis T, editor. New York 2010.
45. AAMC&HHMI. Scientific Foundations for Future Physicians. Washington DC: AAMC, 2009.
46. Summers R; Lieberman J. Training the psychiatrist of the future. Psychiatric News. 2013.
47. Yager J. The practice of psychiatry in the 21st century: challenges for psychiatric education. Acad Psychiatry. 2011;35(5):283–92.
48. Bartels SJ, Lebowitz BD, Reynolds 3rd CF, Bruce ML, Halpain M, Faison WE, et al. Programs for developing the pipeline of early-career geriatric mental health researchers: outcomes and implications for other fields. Acad Med. 2010;85(1):26–35.
49. Insel TR. The Future of Psychiatry (= Clinical Neuroscience). In: NIMH, editor. DIrector's Blog. http://www.nimh.nih.gov/about/director/2012/the-future-of-psychiatry-clinical-neuroscience.shtml2012.
50. NNCI. National Institute of Mental Health (NIMH) Brain Camp. 2015 [03/07/15]; Available from: http://www.nncionline.org/event/national-institute-of-mental-health-nimh-brain-camp/.
51. Fallowfield J. The researcher of the future…engages with industry. Lancet. 2013;381 Suppl 1:S7–8.