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Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness

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Abstract

Background/Purpose. Teamwork involving multiple disciplines is increasingly emphasized in health research, services, education and policy. The terms multidisciplinary, interdisciplinary and transdisciplinary are increasingly used in the literature, but are ambiguously defined and interchangeably used. This paper is the first of two in a series. It discusses the definitions, objectives, and evidence of effectiveness of such teamwork.
Methods. The paper is a literature review based on dictionaries, and Google and MEDLINE (1982-2006) searches.
Results. Multidisciplinarity draws on knowledge from different disciplines but stays within their boundaries. Interdisciplinarity analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole. Transdisciplinarity integrates the natural, social and health sciences in a humanities context, and transcends their traditional boundaries.
The objectives of multiple disciplinary approaches are to resolve real world or complex problems, to provide different perspectives on problems, to create comprehensive research questions, to develop concensus clinical definitions and guidelines, and to provide comprehensive health services. Multiple disciplinary teamwork has both benefits and drawbacks.
Conclusion. The three terms refer to the involvement of multiple disciplines to varying degrees on the same continuum. The common words for multidisciplinary, interdisciplinary and transdisciplinary are additive, interactive, and holistic, respectively. With their own specific meanings, these terms should not be used interchangeably. The more general term "multiple disciplinary" is suggested for when the nature of involvement of multiple disciplines is unknown or unspecified. While multiple disciplinary teamwork is appropriate for complex problems, it is not always necessary in every single project.

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Introduction

There is an increasing emphasis in teamwork that involves multiple disciplines.[1-8] It is generally assumed that efforts to involve more than one discipline are valuable and beneficial.[9-12] Multiple disciplinary approach is emphasized in health research,[13,14] health care services, [15-17] health education,[18-20] and health policy.[21,22] Funding agencies often call for research that involves multiple disciplines.[11,12,23] Hospitals establish multiple disciplinary teams to provide health care. [1,24] Universities establish multiple disciplinary departments and teaching programs.[13] Health policies and programs put their stress on building multiple disciplinary capacity.[21,22]

Terms like multidisciplinary, interdisciplinary, and transdisciplinary have been used to denote efforts that involve several disciplines.[18,25] However, these terms are ambiguously defined[5,9] and often used interchangeably [26] – a situation that Leathard refers to as a "terminological quagmire".[2] Do these terms mean the same or different things? Is there more than one method to bring together people from different disciplines? Are efforts to involve several disciplines really useful? Must we involve multiple disciplines in every project? What are the difficulties in carrying out these efforts? How can this approach be enhanced? However, there has been no previous attempt to comprehensively resolve the confusion.

This paper is a first step to examine the confusing topic. It reviews the definitions of the three terms of interest and then discusses why and under what circumstances multiple disciplinary efforts are useful, with health examples. A second paper will discuss the promotors and barriers, and propose a framework to look for and nurture multiple disciplinary efforts, by locating the place of health sciences in the knowledge universe.

Methods

"Discipline" and the three terms "multidisciplinary", "interdisciplinary", and "transdisciplinary" were looked up in early hard-copy dictionaries from the UK (1944 and 1974),[27,28] US (1975)[29] and Canada (1978),[30] as well as online dictionaries based on "OneLook Dictionary Search"[31] on the Internet.

In addition, Google searches[32], each using one of the three terms of interest plus "definition" as key words, were performed to identify the pertinent online literature on the definitions of the terms, and additional dictionary definitions that "OneLook Dictionary Search" did not locate. Another Google search using all three terms as key words was conducted to find the online literature that include all three terms. Finally, searches of MEDLINE [33] from 1982 to mid-2006 were conducted using a similar strategy to identify relevant publications in the medical and scientific literature.

Results

1. Definitions in the literature

"Discipline" is defined in hard-copy dictionaries as a branch of knowledge,[27,28,30] instruction,[27-30] or learning.[29] Examples are economics and history.[29] "OneLook Dictionary Search" found 19 online dictionaries with English definitions that include the word "discipline". They define "discipline" as a branch of knowledge (10 dictionaries), instruction (5), learning (3), teaching (3) or education (2); or a field of study (3) or activity (1). Examples of a discipline include anthropology, architecture, biology, economics, engineering, history, science, and theology.

The three terms of interest were not found in the 2-volume Oxford Dictionary of 1944,[27] indicating they had probably not been coined at the time (Table 1A). The term "multidisciplinary" was found in the US dictionary of 1975 only, indicating this term probably originated in the US. "Interdisciplinary" was found in all three dictionaries of the 1970's. "Transdisciplinary" was not found in any of the hard copy dictionaries, indicating it is a relatively new term. Dictionaries give the following meanings for the prefixes: Multi - many; more than one. Inter - among; between; mutual, mutually. Trans - across; over; beyond; on the far side of; through.[27-30]

"OneLook Dictionary Search" and additional Google search found 14 online dictionaries with English definitions that include the word "multidisciplinary", 23 dictionaries with the word "interdisciplinary", but only 2 dictionaries with the word "transdisciplinary". Multidisciplinary is defined as "involving" (4 dictionaries) or "of" (4) several disciplines. Interdisciplinary is defined as "involving" (7), "drawing from" (5), "combining" (3), "of" (2), "relating to" (2) or "characterized by" (2) two or more disciplines. The 2 dictionaries, Webster and Merriam-Webster, that defined transdisciplinary, both defined it as interdisciplinary (Table 1A). Thus the 3 terms are rather poorly differentiated in the dictionaries.

Our Internet search found other online documents, mostly glossaries, which define the terms. There is, however, little consistency in definitions of

the three terms, as many of the definitions are virtually interchangeable. Some of the more useful definitions are listed in Table 1B. The earliest online document that defined all three terms was a thesis by Gossman in 1979.[25]

MEDLINE search using the keywords "multidisciplinary interdisciplinary transdisciplinary" found the earliest scientific publication on this topic, written by Thomlinson in 1983, which used the three terms interchangeably.[18] Some definitions in peer-reviewed journals are listed in Table 1C.

TABLE 1. Definitions of multidisciplinary, interdisciplinary and transdisciplinary in the literature.

	A. Dictionary definitions
Multidisciplinary	[Not found] (UK, Oxford, 1944)[27]
	[Not found] (UK, Oxford, 1974)[28]
	Composed of or made up of several specialized branches of learning, as for achieving a common aim (US, Random House, 1975)[29]
	[Not found] (Canada, Funk & Wagnalls, 1978)[30]
	Composed of or combining several usually separate branches of learning or fields of expertise (US, Random House, 1997)[34]
	Involving several academic disciplines or professional specializations (UK, Oxford, 2005)[35]
Interdisciplinary	[Not found] (UK, Oxford, 1944)[27]
	Of more than one branch of learning, e.g. interdisciplinary studies/degrees (UK, Oxford, 1974)[28]
	Combining or involving two or more academic disciplines (US, Random House, 1975)[29]
	Pertaining to or involving two or more branches of knowledge (Canada, Funk & Wagnalls, 1978)[30]
	Combining or involving two or more academic disciplines or fields of study; or two or more professions, technologies, departments, or the like, as in business or industry (US, Random House, 1997)[34]
	Relating to more than one branch of knowledge (UK, Oxford, 2005)[35]
Transdisciplinary	[Not found] (UK, 1944)[27]
	[Not found] (UK, 1974)[28]
	[Not found] (US, 1975)[29]
	[Not found] (Canada, 1978)[30]
	Pertaining to or involving more than one discipline; interdisciplinary (US, Webster, 2006)[36]
	Interdisciplinary (US, Merriam-Webster Online, 2006)[37]
	B. Definitions in the online literature
Multidisciplinary	Group research whereby individuals from different disciplines work together on a common problem, but with limited interaction (Grossman, 1979)[25]
	Relating to or involving several disciplines, such as university, industry, and government (Alberta Inventors and Inventions, 2003)[38]
	Draws on knowledge from different disciplines but stays within the boundaries of those fields (NSERC, 2004)[11]
	A combination of many disciplines in an assignment, not necessarily working in an integrated or coordinated manner (International Rice Research Institute, 2005)[39]
	Involving or combining more than one discipline (University of Southampton, 2005)[40]
	Several branches of medicine, science, or other professions working together toward common goals (Cheshire Medical Center, 2006)[41]
	Involving several areas of medical science and practice (St. Louis Children's Hospital, 2006)[42]
	Of, pertaining to, or arising through the action of many disciplines or professions (Iowa Association of Cardiopulmonary Rehabilitation, 2006)[43]
Interdisciplinary	Joint, coordinated, and continuously integrated research done by experts with different disciplinary backgrounds, working together and producing joint reports, papers, recommendations, and/or plans, which are so tightly and thoroughly interwoven that the specific contributions of each researcher tend to be obscured by the joint product (Grossman, 1979)[25]

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	Involves the interaction among two or more different disciplines and occurs at the inter face between disciplines. This may range from the sharing of ideas to full integration of concepts, methodology, procedures, theory, terminology, data, organization of research and training (NSERC, 2004)[11]
	The ability to analyze, synthesize and harmonize links between disciplines into a coordinated and coherent whole (CIHR, 2005)[12]
	Integrates knowledge and modes of thinking from two or more disciplines - such work embraces the goal of advancing understanding in ways that would have not been possible through single disciplinary means (Mansilla and Gardner, 2005)[44]
	A group of professional specialists with expertise in different resources that collaborate to develop and evaluate management alternatives (US Department of Agriculture, 2005)[45]
	At the interface between more than one discipline (University of Southampton, 2005)[40]
	Work which integrates concepts across different disciplines. New disciplines have arisen as a result of such syntheses (Wikipedia, 2006)[46]
	Comprehensive, concerning the cooperation of several disciplines, e.g. physicists with medical practitioners and others (RayMaster International, 2006)[47]
	A course or instructional program involving concepts, knowledge, or faculty from several disciplines (Oregon State University, 2006)[48]
Transdisciplinary	Group research whereby individuals from different disciplines work as a team within a mutually accepted systems organization with an overall set of systems goals (Grossman, 1979)[25]
	An approach that occasions the emergence of new data and new interactions from out of the encounter between disciplines. It offers us a new vision of nature and reality. Trandisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them (Charter of Transdisciplinarity, 1994)[49]
	A specific form of interdisciplinarity in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from different scientific disciplines as well as non-scientific sources are integrated (Vrije University Amsterdam, 2005)[50]
	Of relevance to more than one discipline (University of Southampton, 2005)[40]
	Investigators with different disciplinary backgrounds know enough about other perspectives (conceptually, methodologically, statistically, substantively) to be able to work as a team to study a problem using shared perspectives informed by a range of disciplines (Centre for Addiction and Mental Health, 2006)[51]

C. Definitions in peer-reviewed publications

Multidisciplinary	Multidisciplinary projects are those in which researchers representing different fields contribute methods and ideas from their respective disciplines toward the analysis of a particular research question (Rosenfield, 1992)[52]
	In a multidisciplinary team, health care providers tend to treat patients independently and to share information with each other, while the patient may be a mere recipient of care (Bernard-Bonnin et al, 1995)[53]
	In multidisciplinary research, a variety of disciplines collaborate in one research program without integration of concepts, epistemologies, or methodologies. The degree of integration between disciplines is restricted to the linking of research results (Flinterman et al, 2001)[54]
Interdisciplinary	Interdisciplinary projects involve closer and more frequent collaborative exchanges among researchers drawn from different fields who are working together on a common problem (Rosenfield, 1992)[52]
	An interdisciplinary team aspires to a more profound level of collaboration (than a multi disciplinary team), in which constituents of different backgrounds combining their knowledge mutually complete different levels of planned care (Bernard-Bonnin et al, 1995)[53]
	Interdisciplinary research is a collaboration of several disciplines, but in this case concepts, methodologies, or epistemologies are explicitly exchanged and integrated, resulting in a mutual enrichment (Flinterman et al, 2001)[54]
Transdisciplinary	Transdisciplinary projects are those in which researchers from different fields not only work closely together on a common problem over an extended period but also create a

shared conceptual model of the problem that integrates and transcends each of their sepa rate disciplinary perspectives (Rosenfield, 1992)[52]

Transdisciplinary approaches to human health are defined as approaches that integrate the natural, social and health sciences in a humanities context, and in so doing transcend each of their traditional boundaries (Soskolne, 2000)[55]

Transdisciplinarity is a specific form of inter disciplinarity in which boundaries between and beyond disciplines are transcended and knowledge and perspectives from different scientific disciplines as well as non-scientific sources are integrated (Flinterman et al, 2001)[54]

Multidisciplinarity, Interdisciplinarity, and Transdisciplinarity

"Multidisciplinarity", according to Klein, is a process for providing a juxtaposition of disciplines that is additive, not integrative; the disciplinary perspectives are not changed, only contrasted.[56] An example is physics and history, biology and architecture.[104] A painting by Giotto can be studied not only within art history but also within history of religions, European history, and geometry.[57] Team-taught courses in which faculty provide serial lectures are often multidisciplinary.[58] In a multidisciplinary team dealing with pediatric undernutrition, members function as independent specialists rather than interactive team members. The child or the family is assessed individually by several professionals (such as nursing, social work, psychiatry, nutrition, education, etc) but generally at the discretion of the team leader, usually a physician in medical settings.[24]

"Interdisciplinarity" is a synthesis of two or more disciplines, establishing a new level of discourse and integration of knowledge.[56] For example, when nuclear physics is combined with medicine it leads to new treatments for cancer. When methods from mathematics were transferred to physics, mathematical physics was born, and when they were transferred to meteorological phenomena or stock market processes, they gave rise to chaos theory; transferring methods from particle physics to astrophysics produced quantum cosmology; and from the transfer of computer methods to art, computer art was generated.[57] Interdisciplinary efforts can create new disciplines.[46] For instance, quantum information processing amalgamates elements of quantum physics and computer science; bioinformatics combines molecular biology with computer science.[46] Other examples are biochemistry, ecophilosophy and astrophysics;[59] and psychoimmuno-neuroendocrinology.[60] In an interdisciplinary pediatric undernutrition team, members come together as a whole to discuss their individual assessments and develop a joint service plan for the child.[24]

"Transdisciplinarity" provides holistic schemes that subordinate disciplines, looking at the dynamics of whole systems.[56] Examples are structuralism and Marxism.[58] A transdisciplinary approach on an issue such as pollution or hunger both within and beyond disciplinary boundaries can lead to new perspectives.[59] Ecological economics, defined as the study of the relationship between human housekeeping (economics) and nature's housekeeping (ecology), is transdisciplinary.[61] It is more than drawing on the disciplines of economics and ecology, and requires a common perspective that "transcends" those that are standard in the two disciplines. The traditional perspective of economics needs to be modified to take on board the fact that humans are a species of animal; and the traditional perspective of ecology needs to recognise the role of humanity as a species in the functioning of all ecosystems.[61] In a transdisciplinary pediatric undernutrition team, members share roles as each specialist helps other members to acquire skills related to the specialist's area of expertise; this requires both role release (accepting that others can do what the specialist was trained specifically to do) and role expansion (allowing that one's job can include more than what one was specifically trained to do)[24].

Several authors contrast the three terms (Table 2). According to Rosenfield,[52] multidisciplinary teams work in parallel or sequentially from their specific disciplinary base to address a common problem. Interdisciplinary teams work jointly but still from a discipline-specific base to address a common problem. Transdisciplinary teams work using a shared conceptual framework, drawing together discipline-specific theories, concepts, and approaches to address a common problem. Young[66] suggested that in multidisciplinary teams the different professions work to individually set goals and meet to discuss their progress. In interdisciplinary teams goals are first agreed by the team, whose members then coordinate their input to the common project plan. In transdisciplinary teams, not only goals but skills are shared.

Pain describes the process of evolving approaches to involve several disciplines.[72] Multidisciplinarity is

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TABLE 2. Comparison of multidisciplinary, interdisciplinary and transdisciplinary

Multidisciplinary	*Interdisciplinary*	*Transdisciplinary*
Working with several disciplines[9]	Working between several disciplines[9]	Working across[9,57] and beyond[57] several disciplines
Involves more than two disciplines[62,63]	Involves two disciplines[62,63] (i.e. focuses on reciprocal action of disciplines[64])	Involves scientists from relevant disciplines, as well as stakeholders,[61] nonscientists,[54] and non-academic participants[6]
Members from different disciplines working independently on different aspects of a project,[65] working in parallel or sequentially[52]	Members from different disciplines working together on the same project;[65] working jointly[52]	Members from different disciplines working together using a shared conceptual framework[52]
Individual goals in different professions[66]	Shared goals[66]	Shared goals and shared skills[66]
Participants have separate but inter-related roles[5]	Participants have common roles[67]	Participants have role release and role expansion[24]
Participants maintain own disciplinary roles[56,67]	Participants surrender some aspects of their own disciplinary role;[3,5,68] but still maintains a discipline-specific base[52]	Participants develop a shared conceptual framework, drawing together discipline-specific bases[52]
Does not challenge disciplinary boundaries[67]	Blurring of disciplinary boundaries[3]	Transcend the disciplinary boundaries[52,54,55,61]
Summation[5] and juxtaposition[56,69,70] of disciplines	Integration[5,71] and synthesis[56,70] of disciplines	Integration, amalgamation, assimilation, incorporation, unification and harmony of disciplines, views and approaches[60]
Additive,[56] Integrative,[54] Collaborative[54]	Interactive,[11] Integrative,[5,6,11,25,44,46,54,56,60,71] Collaborative[45,52-54]	Holistic,[56,72,73] Transcendental,[50,52,54,55] Integrative,[6,50,52,54,55,60] Collaborative[14]
Graphically analogous to two totally separate circles[59]	Graphically analogous to two partially overlapping circles[59]	Graphically analogous to a third circle that covers two partially overlapping circles[59]
External coherence (i.e. motivated by a desire to focus on clients' needs[5])	Internal coherence[9] (i.e. motivated by a desire to focus on team needs)	
Participants learn about each other[5]	Participants learn about and from each other[5]	
Separate methodologies[54,67,74]	Common methodologies[3,68]	
Instrumental[9]; use of complementary knowledge or perspectives to address a question[11]	Epistemological;[9,68] creation of new knowledge or perspective, even new disciplines[11,46]	
The outcome is the sum of the individual parts[5,75]	The outcome is more than the sum of the individual parts[5,75]	
Graphically analogous to a horizontal series of compartments, each linked by a vertical unidirectional arrow to a higher "control" compartment above[25]	Graphically analogous to a horizontal series of compartments, each linked by a vertical unidirectional arrow to a higher "control" compartment above; and also with horizontal bidirectional arrows between pairs of horizontal compartments[25]	

an approach when experts from different fields work together on a common subject within the boundaries of their own disciplines. However, if they stick to those boundaries they may reach a point where the project cannot progress any further. They will then have to bring themselves to the fringes of their own fields to form new concepts and ideas, and create a whole new, interdisciplinary field. A transdisciplinary team is an interdisciplinary team whose members have developed sufficient trust and mutual confidence to transcend disciplinary boundaries and adopt a more holistic approach.[72]

The Holistic Education Network presents four graphical schemes. "Disciplinary" is visualized as a single circle; "multidisciplinary" is represented by two totally separate circles; "interdisciplinary" is two partially overlapping circles; and "transdisciplinary" is a third circle that covers two partially overlapping circles.[59]

Multidisciplinarity and Interdisciplinarity

According to Pirrie et al[68] the distinction between interdisciplinary and multidisciplinary is based upon three dimensions: numerical, territorial, and epistemological. For the numerical dimension, interdisciplinary involves only two disciplines, and becomes multidisciplinary if more than two disciplines are involved[62,63] (Table 2). Although this may on surface seem like a numbers game[68], interdisciplinary actually focuses on the reciprocal action of two disciplines.[64] For the territorial (or disciplinary boundary) dimension, multidisciplinary often involves little interaction or collaboration across disciplines, like "one sees different facets of a crystal by turning it".[67] Interdisciplinary, on the other hand, is like "you are crossing into another space",[68] and there is blurring of the professional boundaries.[3] For the epistemological dimension, interdisciplinary involves the creation of a new way of working.[68]

Transdisciplinary

Kerne summarized the process to achieve transdisciplinarity.[76] "Trans-" means "across, to or on the farther side of, beyond, over".[77] To go across, beyond, and over disciplinary boundaries, there is a process to assemble disciplines and recombine information. Juxtaposition is a starting point for integration.[69] Juxtaposition and recontextualization draw the mind to puzzle about potential connection between information elements. The next step is recombinant information.[76] Recombination is "the process of taking existing coded compositions, breaking them down into constituent elements, and recombining those elements to form new codings",[76] or new knowledge. When information elements are recombined, if a combination makes sense immediately, the cognitive process is not likely to go anywhere. But, if there are potential relationships that are not immediately clear, the mind tends to work on making sense of them, to find new connections. Sometimes, this process does not lead anywhere. On other occasions, one experiences "Ah-ha!". This is emergence of new ideas and knowledge. Therefore, ambiguous and incongruous juxtaposition of heterogeneous information elements that are related through the operation of a transdisciplinary interface is likely to stimulate the emergence of new knowledge.[76]

A Team

According to Lorimer and Manion, "a team is a small number of consistent people committed to a relevant shared purpose, with common performance goals, complementary and overlapping skills, and a common approach to their work".[78] According to Wiecha and Pollard, an interdisciplinary team is a consistent grouping of people from relevant disciplines, whose interactions are guided by specific team functions and processes to achieve team-defined favourable outcomes.[79] Conventional teams are those whose members interact through traditional meetings and consultations. With modern technology, however, the Internet rapidly becomes a logical platform for supporting interdisciplinary teamwork.[79] Electronic teams are those whose members interact through new communications processes augmented by advances in electronic technology, such as the Internet, Web-based tools, multifunctional software applications, digital audio and video access, lists, forums and websites, that enables teamwork to occur anywhere, at any time.[79,80]

2. Why Pursue Multiple Disciplinarity?

There are several reasons that teamwork involving multiple disciplines are desirable.

To resolve a real world problem

Life is multiple disciplinary. Disciplines are the result of artificial fragmentation of knowledge. Real world problems are rarely confined to the artificial boundaries of academic disciplines.[81] Multiple disciplinary research evolves to meet the demands of many societal, environmental, industrial, scientific and engineer-

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ing problems that cannot be adequately addressed by single disciplines alone.[11] There are real world problems and issues that are broader than any single discipline, and can be fruitfully examined in a multiple disciplinary framework.[82]

To resolve a complex problem

In the olden days, problems were relatively simple. A person could build a horse drawn cart or a sail boat by knowing the six simple machines (lever, pulley, wheel and axle, inclined plane, wedge, and screw).[83] With modern technology, however, such thorough knowledge is no longer possible or necessary. Modern automobiles and ocean liners must be built by teams of experts from different disciplines, who themselves can understand and contribute to only a small part of the complex problems.[83] The requirement for multiple disciplinarity is emerging at a time when pace and complexity of science and technology is accelerating, such as in the fields of bioinformatics, hydrogen fuel cells, and broadband infrastructure.[84] Multiple disciplinary teams, with people trained in different fields, are common in complex environments such as research,[11,12,44,80,85] health care,[46,79] teaching,[44,81,82,86] and public health.[9,21]

To provide different perspectives on a problem

Experts from different disciplines read things differently. Quoting from Bernd, "We observe and react to data within the structure of our subject. We read books as 'Englishers' because that is what we are. Quite obviously an historian would not read books in the same manner. In certain sense, he would not be reading the same books".[86]

To create a comprehensive prospective theory-based hypothesis for research

It is necessary to develop "the right question" to lead research.[87] Explicit use of biomedical theory (e.g. sex, physiology) and inexplicit use of social theory (e.g. gender, social capital) to generate hypotheses for test by public health research requires a comprehensive multiple disciplinary approach.[88] After data have been collected and analysed, use of post-hoc theories to explain findings also requires a similar approach. Furthermore, individual disciplines can get "tired", become predictable, and then a crisis of ideas can ensue, after which, progress is difficult.[89] Multiple disciplinary approaches can give the research a "look in" from many different stances at issues in research and reduce "one dimensional" evaluation.[10]

To develop consensus clinical definitions and guidelines for complex diseases and conditions

Consensus of multidisciplinary clinicians is often required to develop definitions for complex diseases such as idiopathic interstitial pneumonias,[90,91] and complex conditions such as multiple chemical sensitivity.[92] For example, the joint American Thoracic Society and European Respiratory Society international consensus definition for idiopathic interstitial pneumonias was worked out by an international multidisciplinary core panel of some 20 pulmonologists, pulmonary pathologists, and thoracic radiologists, and was then approved by an extended review panel of some 65 experts from over 20 countries.[90,91]

To provide comprehensive services such as health care and health education

Multiple disciplinary teamwork is required in health and social care, such as primary health care,[1] education in health care,[4,5,68] and training of medical, dental and nursing students.[19,62,64] Such teamwork can offer a coordinated range of skills, expertise and clinical experience in a setting of interprofessional support.[66] Multidisciplinarity is in some cases required by law[93,94] or guidelines.[95] For example, the US federal Public Law 101-630, the Indian Child Protection and Family Violence Prevention Act, states that "each multidisciplinary team established under this section shall include, but is not limited to, personnel with a background in 1) law enforcement, 2) child protective services, 3) juvenile counselling and adolescent mental health, and 4) domestic violence".[94] In Australia, the multidisciplinary care team for women with breast cancer must minimally include surgery, oncology, pathology, radiology and supportive care.[95] A multidisciplinary team, consisting of an ophthalmologist and an educator, is recommended for comprehensive services to myopic children in developing countries.[96]

3. Teamwork Effectiveness

Some evidence has emerged demonstrating teamwork benefit.[7,97-112] The purported benefits of teamwork include increased learning and development of people and organizations, better utilization of resources and planning for the future, minimization of unnecessary costs, and improving job performance and work quality.[101] Benefits also include discussions among participants, networking, teamwork, gaining new insights and skills, publications, merit points, and a positive effect on careers.[6] In a study of the effect of coordination dimensions (including communication, shared

goals, shared knowledge, problem solving and mutual respect) in orthopedic surgical care, it was found that the more coordination the team demonstrated, the better the patients' postoperative functioning and the shorter the hospital stays.[102] Teamwork for collaborative care and shared care has been shown to improve patient outcomes.[104] In psychiatric disorders management, it has been shown that multidisciplinary care models that include patient education, psychiatric and primary care co-management improve patient outcomes.[105] Patients with depression rated the quality of their care more highly,[106,107] were more adherent to medications,[105,108] had fewer symptomatic days,[109,110] and had decreased depression scores[107,111] when treated collaboratively. Similar results have been reported with panic disorder.[112] How these collaborative models improve outcomes, however, is not clear.

4. Teamwork Ineffectiveness

Other studies provide conflicting results on the effectiveness of teamwork. For example, a literature review reported weaknesses in research rigor, with great inconsistency in terminology and little empirical evidence for the effectiveness of interdisciplinary teams.[113] Another literature review rated the state of interdisciplinary teamwork as poor.[114]

Proposed Definitions

Based on a review of Table 1, we recommend the following definitions:

Multidisciplinarity draws on knowledge from different disciplines but stays within the boundaries of those fields (NSERC, 2004).[11]

Interdisciplinarity analyzes, synthesizes and harmonizes links between disciplines into a coordinated and coherent whole (CIHR, 2005).[12]

Transdisciplinarity integrates the natural, social and health sciences in a humanities context, and in so doing transcends each of their traditional boundaries (Soskolne, 2000).[55]

Based on a review of Table 2, we propose that the terms "multidisciplinary", "interdisciplinary" and "transdisciplinary" are to be used to describe multiple disciplinary approaches to varying degrees on the same continuum.

We further propose that when the exact nature of a multiple disciplinary effort is not known, the specific terms "multidisciplinary", "interdisciplinary" and "transdisciplinary" should be avoided, and the general term "multiple disciplinary" used instead.

Discussion

This paper, the first of two in a series, serves to clarify the terms "multidisciplinary", "interdisciplinary" and "transdisciplinary". In our literature review, these terms are found to be relatively new, poorly differentiated even in dictionaries, confusing and often used interchangeably among many authors, but starting to converge or "gel" towards certain specific meanings.

We conclude that the three terms are used by many authors to refer to the involvement of multiple disciplines to varying degrees on the same continuum. Multidisciplinary, being the most basic level of involvement, refers to different (hence "multi") disciplines that are working on a problem in parallel or sequentially, and without challenging their disciplinary boundaries. Interdisciplinary brings about the reciprocal interaction between (hence "inter") disciplines, necessitating a blurring of disciplinary boundaries, in order to generate new common methodologies, perspectives, knowledge, or even new disciplines. Transdisciplinary involves scientists from different disciplines as well as nonscientists and other stakeholders and, through role release and role expansion, transcends (hence "trans") the disciplinary boundaries to look at the dynamics of whole systems in a holistic way.

Through this review, we believe that common everyday words that can be used to describe the nature of multidisciplinary, interdisciplinary, and transdisciplinary are additive (serving or tending to increase[30]), interactive (producing action on each other[30]), and holistic (producing a material object that has a reality other and greater than the sum of its constituent parts[30]), respectively (Table 3). Mathematically, multidisciplinary is analogous to 2+2=4115 (additive116, as in linear combination); interdisciplinary is analogous to 2+2=5117 (deviation from linear combination, thus requiring an interaction term in a linear model116,118); and transdisciplinary is analogous to 2+2=yellow119 (where the outcome is of a different kind). To these, we add our everyday food examples: multidisciplinary is like a salad bowl (such

TABLE 3. The authors' views on multidisciplinary, interdisciplinary and transdisciplinary

	Multidisciplinary	*Interdisciplinary*	*Transdisciplinary*
Keyword	Additive	Interactive	Holistic
Mathematical example	2+2=4	2+2=5	2+2=yellow
Food example	a salad bowl	a melting pot	a cake

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as a vegetable platter or mixed salad, in which the ingredients remain intact and clearly distinguishable); interdisciplinary is like a melting pot (such as a fondue or stew, in which the ingredients are only partially distinguishable); transdisciplinary is like a cake (in which the ingredients are no longer distinguishable, and the final product is of a different kind from the initial ingredients).

Because multidisciplinary, interdisciplinary, and transdisciplinary are starting to gain specific meanings in the literature, we suggest that the use of these terms should be restricted to describe specific approaches with a known or specified level/nature of involvement of multiple disciplines. For the more general situation, the term "multiple disciplinary" should be used when the level/nature of involvement of multiple disciplines is unknown or unspecified.

There is little documented evidence in the literature about the effectiveness of multiple disciplinary teamwork. The limited available evidence indicates conflicting results. In theory, multiple disciplinary approaches are necessary to resolve real world, complex problems. Multiple disciplinary teamwork can provide different perspectives on a problem by generating comprehensive prospective hypotheses before a study, and providing comprehensive post-hoc theories to explain study results. Multiple disciplinary teams have been found with success in situations such as consensus clinical definitions for complex diseases, and comprehensive health care services and health education.

Multiple disciplinary teamwork does not always work, nor does it always deliver what it promises to deliver. Obviously it is not necessary to involve multiple disciplines in every single project. Some projects are so simple and straightforward that they are best performed by one person, or experts from one discipline. Other projects may be more complex and require multiple disciplines, but the expertise may not be available, or even exist. During the project, team conflicts, discipline conflicts and other factors can lead to failure.

A second paper will examine the promotors and barriers for multiple disciplinary teamwork, under what conditions and by what criteria multiple disciplinary efforts are called for, and ways to look for and nurture multiple disciplinary efforts.

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