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REPRESENTATIONAL MEASUREMENT FAILURE IN HEALTH TECHNOLGY ASSESSMENT

CANADA: UNIVERSITY RESEARCH CENTERS AND THE ABSENCE OF MEASUREMENT IN HTA EDUCATION

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ABSTRACT

Previous investigations of the Canadian health technology assessment (HTA) knowledge base have consistently demonstrated two closely related phenomena: measurement inversion and curriculum inversion. Across Canadian HTA agencies, research institutions, and educational programs, the scientific principles governing quantitative measurement receive little or no recognition, while utilities, multiattribute utility instruments, quality-adjusted life years (QALYs), cost-effectiveness analysis, and simulation-based economic evaluation are treated as though they provide scientifically valid quantitative evidence. These findings raise an important question. If the Canadian HTA knowledge base consistently exhibits measurement inversion, where does this inversion originate?

The present investigation examines the educational foundations of Canadian HTA by evaluating the publicly available curricula of Canada's leading university-based programs in health economics and health technology assessment. Five major academic centers were assessed using a common analytical framework derived from the axioms of representational measurement. The review examined whether students are first introduced to the scientific requirements for quantitative measurement, including the principle that measurement must precede arithmetic, ratio measurement, admissible transformations, dimensional homogeneity, and the distinction between manifest and latent attributes, before proceeding to the conventional methods of health technology assessment.

Across all institutions, a consistent pattern emerged. Extensive instruction is provided in health economics, economic evaluation, cost-effectiveness analysis, decision analysis, health technology assessment, and related analytical methods. However, no evidence was identified that representational measurement provides the scientific foundation for these quantitative methods. Core concepts essential to lawful quantitative inquiry including ratio measurement, admissible arithmetic, linear ratio measures for manifest attributes, Rasch logit ratio measures for latent attributes, and the measurement of possession of latent attributes were absent from the publicly available curricula.

These findings demonstrate program content inversion as the immediate educational mechanism through which curriculum inversion and measurement inversion are reproduced within Canadian HTA. Students are introduced to increasingly sophisticated numerical methods without first establishing whether the quantities entering those methods satisfy the scientific conditions required for quantitative measurement. The consequence is an educational framework in which arithmetic precedes measurement rather than follows it.

The implications extend beyond Canadian universities. These programs educate the researchers, health economists, and policy analysts who contribute to reimbursement submissions and to assessments undertaken by Canada's Drug Agency, provincial HTA organizations, and related decision-making bodies. If representational measurement is absent from the educational foundation, then the scientific validity of subsequent quantitative claims concerning therapy impact is necessarily compromised. The findings indicate that correcting Canadian HTA requires

more than methodological refinement. It requires reconstruction of the curriculum so that representational measurement, and in particular the two lawful forms of ratio measurement, linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes, becomes the indispensable foundation upon which all subsequent quantitative analysis is built.

INTRODUCTION

A series of previous investigations of the Canadian health technology assessment (HTA) knowledge base has identified two closely related patterns. Measurement inversion was demonstrated by the inverted endorsement of statements concerning the scientific requirements for quantitative measurement [1]. Statements affirming that measurement must precede arithmetic, that admissible mathematical operations depend upon the properties of the measurement scale, that quantitative claims require unidimensional attributes, and that manifest and latent attributes require different forms of measurement received consistently weak endorsement. Conversely, statements treating utilities, multiattribute utility instruments, quality-adjusted life-years (QALYs) and simulation-based cost-effectiveness models as scientifically valid quantitative methods received consistently strong endorsement. Curriculum inversion described the corresponding pattern within the Canadian educational knowledge base [2]. The concepts that define representational measurement were either absent or only weakly endorsed, while the conventional concepts underpinning contemporary HTA received consistently strong endorsement [3].

These findings naturally invite a further question. If measurement inversion and curriculum inversion characterize the Canadian HTA knowledge base, where do these patterns originate? A logical next step is to examine the content of the university programs through which health economics and HTA are introduced and developed. Educational knowledge bases do not arise independently of the programs from which they are derived. The topics selected, the concepts emphasized, the sequence in which methods are presented, and the standards adopted for evaluating quantitative claims together determine the intellectual framework subsequently reproduced in research, policy and professional practice. The present investigation therefore asks whether the publicly available content of Canadian university programs is consistent with, and may help explain, the previously demonstrated patterns of measurement inversion and curriculum inversion.

This is not the first investigation of program inversion. Similar patterns of measurement and curriculum inversion were observed in Australia and New Zealand. Subsequent assessments of program content for HTA university associated HTA research groups then found a significant program content inversion which neglected representational measurement and the importance of ratio measurement in establishing valid claims for therapy impact [4 5] .

This question is particularly important because the influence of Canadian HTA education extends well beyond the classroom. University programs educate the researchers, health economists, analysts and policy advisers who subsequently contribute to health technology assessment throughout Canada. Their graduates undertake academic research, prepare reimbursement submissions, develop methodological guidance and contribute directly or indirectly to assessments undertaken by Canada's Drug Agency (CDA), the Institut national d'excellence en santé et en services sociaux (INESSS), provincial health technology assessment organizations and hospital-based assessment units. These organizations play central roles in determining which medicines, devices and health technologies receive public funding and reimbursement within Canada's publicly financed health care system. The analytical framework established through university education therefore has direct implications for the evidence and methods that support reimbursement decisions and the allocation of finite health care resources across Canada.

If the educational framework supporting that evidence fails to recognize the scientific conditions required for quantitative measurement, the implications extend well beyond education itself. Decision makers necessarily assume that the quantitative claims presented to them are supported by admissible measures. Cost-effectiveness ratios, QALYs, model outputs and reference-case simulations can provide scientifically meaningful evidence only if the quantities from which they are derived satisfy the requirements of representational measurement. Where those requirements are absent, no degree of statistical sophistication or mathematical complexity can compensate for the lack of lawful measurement. The scientific integrity of Canadian health technology assessment therefore depends ultimately upon the measurement standards embedded within the educational framework from which HTA practice is derived. The Canadian context is particularly important because one of the world's most influential multiattribute utility instruments, the Health Utilities Index (HUI), originated in Canada and has played a major role in the international acceptance of utilities and QALYs. The educational framework that supports these methods is therefore of international as well as national significance.

The present investigation parallels previous assessments of university-based HTA and health economics programs in Australia and New Zealand. The Canadian review examines the publicly available educational and research content associated with the five university-based institutions that collectively represent Canada's principal academic capacity in health economics, outcomes research and health technology assessment. These comprise the School of Population and Public Health at the University of British Columbia; the School of Public Health at the University of Alberta, including its Graduate Embedded Certificate in Health Economic Evaluation; the Health Research Methodology Program at McMaster University with its specialization in Health Technology Assessment; the Institute of Health Policy, Management and Evaluation at the University of Toronto; and the École de santé publique de l'Université de Montréal with its dedicated graduate programs in health technology assessment. Together these institutions provide Canada's principal university-based educational infrastructure supporting health economics and HTA. Their graduates populate academic research, government agencies, consultancy groups, provincial assessment organizations and the wider health policy community, making their educational frameworks an important determinant of the analytical methods and concepts that ultimately inform Canadian HTA practice.

As in the previous investigations, this question is examined through AI large language model interrogation of publicly available educational knowledge bases. Program descriptions, curricula, course outlines, teaching materials, methodological guidance and associated research outputs collectively define the conceptual framework presented by each institution. Rather than evaluating isolated topics, the interrogation applies two contrasting sets of canonical standards. The first captures the scientific requirements of representational measurement, including the principle that measurement must precede arithmetic, the properties of the scales of measurement, ratio measurement, dimensional homogeneity, and the distinction between manifest and latent attributes together with their respective requirements for measurement. The second captures the concepts that characterize contemporary HTA, including utilities, multiattribute utility instruments, QALYs, cost-effectiveness modelling, decision analysis, Markov models, probabilistic sensitivity analysis, reference-case simulation and related analytical methods.

These two conceptual frameworks are mutually exclusive. Acceptance of the standards of representational measurement necessarily precludes acceptance of contemporary HTA as a scientifically valid framework for quantitative claims because the latter depends upon numerical constructions that do not satisfy the conditions required for admissible arithmetic. Conversely, endorsement of contemporary HTA necessarily implies the rejection, whether explicit or implicit, of the scientific requirements of representational measurement. The interrogation therefore asks a straightforward question: which of these competing conceptual frameworks is represented in the publicly available content of Canada's leading university programs in HTA and health economics?

The objective is not to evaluate institutional quality or teaching performance. Rather, it is to determine which conceptual framework these programs endorse as the scientific foundation for quantitative claims. If representational measurement is absent while the conventional HTA framework dominates program content, then curriculum inversion provides a plausible explanation for the previously demonstrated patterns of measurement inversion and curriculum inversion within Canada. If, however, representational measurement is found to underpin these programs, the earlier conclusions regarding measurement inversion and curriculum inversion would require reconsideration.

FOUNDATIONS OF QUANTITATIVE ANALYSIS

Before proceeding to the analysis of program content, it is important to identify the scientific principles against which that content must be interpreted. The purpose is not to prejudge the findings of the investigation but to make explicit the standards that define lawful quantitative inquiry throughout the physical and social sciences. These standards have been established for many decades through the theory of representational measurement and are not matters of methodological preference or competing philosophical opinion. They are the conditions that determine whether quantitative claims are scientifically admissible.

Two principles are fundamental. First, measurement must precede arithmetic. Numerical operations are permissible only after the attribute of interest has been shown to possess the properties required for quantitative measurement. Arithmetic cannot create measurement where measurement does not already exist. Second, the arithmetic operations employed must be admissible for the scale on which the attribute has been measured. In practice, claims involving multiplication, division, averaging, ratios and other quantitative comparisons require ratio measurement. For health technology assessment, this requirement can be satisfied in only two ways: by a linear ratio measure for manifest attributes or by a Rasch logit ratio measure for latent attributes. No alternative measurement framework satisfies these requirements.

These principles are not optional and they are not open to negotiation. They define the boundary between numerical description and quantitative science. While contemporary HTA has developed a body of methods founded upon utilities, QALYs and simulation modelling, the present investigation is not concerned with defending or criticizing those methods as matters of policy preference. Rather, it asks a prior scientific question: do Canadian university and related HTA programs acknowledge the measurement principles that govern all quantitative inquiry, or do they present an alternative framework that proceeds without first establishing the conditions required for valid arithmetic? It is this question that guides the analysis that follows.

MEASUREMENT BEFORE ARITHMETIC

Before students are introduced to health technology assessment, health economics, outcomes research, cost-effectiveness analysis or decision modelling, they should first be introduced to the scientific principles that determine whether any quantitative claim is possible [6 7] This is not a matter of pedagogical preference but of scientific necessity. Every quantitative discipline, whether in the physical, biological, or social sciences, is founded upon the prior establishment of measurement. Arithmetic is meaningful only when applied to quantities that have first been shown to satisfy the requirements of measurement. Consequently, the first responsibility of any HTA curriculum is not to teach methods for manipulating numbers, but to teach the conditions under which numbers represent measurable attributes.

For more than eighty years these principles have defined the accepted scientific standards for quantitative measurement through the theory of representational measurement. They are not optional methodological conventions but the universally accepted conditions governing quantitative inquiry across the physical and social sciences. An attribute must first be identified and defined. It must then be demonstrated that observations of that attribute satisfy the axioms necessary for quantitative representation. Only after these conditions have been established can numerical values be assigned and arithmetic operations justified. The sequence is therefore unambiguous: identify the attribute, establish measurement, then undertake arithmetic. Reversing this order produces numerical results that have no scientific interpretation, regardless of the sophistication of the statistical or economic methods subsequently applied.

An HTA curriculum that claims to prepare scientists and policy analysts must therefore begin with representational measurement, the scales of measurement, admissible transformations, dimensional homogeneity, and the distinction between manifest and latent attributes. These concepts provide the framework within which every subsequent quantitative claim is judged. Without them, students cannot distinguish between numbers that represent measurable quantities and numbers that merely label categories or order preferences. The consequence is that sophisticated computational methods become detached from the scientific requirements that justify their application.

Once these foundations have been established, the educational pathway becomes remarkably simple. There are only two admissible forms of ratio measurement capable of supporting quantitative claims for therapy impact. Which form is required depends entirely upon the nature of the attribute under investigation.

The first concerns manifest attributes. These are attributes that can be observed directly and measured using conventional physical or operational procedures. Examples include survival time, hospital admissions, emergency department visits, doses administered, days receiving therapy, laboratory concentrations, tumor dimensions, or walking distance. Such attributes possess observable units, a true zero, and permit the construction of linear ratio scales. Because equal intervals represent equal quantities and zero represents the complete absence of the attribute, all arithmetic operations, including multiplication and division, are admissible. Therapy claims expressed in terms of these measures are therefore directly evaluable and capable of empirical replication.

The second concerns latent attributes. These attributes cannot be observed directly because they represent underlying constructs such as pain severity, physical functioning, fatigue, anxiety, depression, quality of life, or need fulfilment. Unlike manifest variables, latent attributes cannot be measured simply by assigning numerical values to questionnaire responses or summing item scores. Their existence and measurement require a formal measurement model capable of demonstrating that the observed responses reflect a single underlying quantitative continuum.

The only measurement framework that satisfies these requirements is the Rasch measurement model [8]. Rasch analysis does not begin by assuming that questionnaire scores constitute measurements. Instead, it asks whether the responses are consistent with the existence of a unidimensional latent attribute that can be measured independently of the particular sample of respondents or the particular items employed. Through conjoint estimation of persons and items, the Rasch model constructs an invariant continuum upon which both persons and items can be located. Only when the data satisfy the requirements of the model can the resulting estimates be interpreted as measures.

This distinction is fundamental because the objective of Rasch measurement is not the production of questionnaire scores. Its objective is the measurement of an individual's possession of a latent attribute. The latent attribute is the quantity of scientific interest; the questionnaire responses merely provide observable evidence from which that quantity may be estimated. The resulting person location on the Rasch continuum represents the individual's degree of possession of the defined latent attribute, while the item locations represent the relative amount of the attribute required to endorse each item. Measurement is therefore achieved through the interaction between persons and items, not through the arithmetic aggregation of responses.

The concept of possession distinguishes Rasch measurement from both conventional psychometrics and general item response theory. Summed scores describe patterns of responses but do not establish that the underlying attribute has been measured. Similarly, statistical models that estimate person parameters without satisfying the measurement requirements embodied in the Rasch model do not necessarily produce measures possessing the invariance required by representational measurement. Rasch is unique because its objective is the construction of an invariant ruler capable of measuring the quantity of a latent attribute possessed by each individual. The emphasis is therefore on measurement rather than statistical description.

Once this distinction is understood, the educational implications are immediate. Every HTA curriculum should teach that claims involving manifest attributes require linear ratio measurement, while claims involving latent attributes require Rasch logit ratio measurement. There is no third category. Utilities, preference scores, composite indices, and other numerical constructions do not become quantitative measures simply because they are expressed numerically or incorporated into increasingly sophisticated statistical models. Their admissibility depends entirely upon whether they satisfy the requirements of representational measurement.

The implications for New Zealand HTA education are therefore straightforward. If university and related HTA programs are to provide the scientific foundations for evidence that ultimately informs PHARMAC funding and reimbursement decisions, students should first learn what constitutes a measurable attribute, how ratio measures are established, why measurement must precede arithmetic, and why latent attributes require Rasch logit ratio measurement to establish possession. Only after these foundations have been mastered should they proceed to decision analysis, cost-effectiveness analysis, utilities, simulation models and reimbursement frameworks. Without this sequence, quantitative methods become detached from the scientific principles that alone justify their application. A New Zealand HTA curriculum that fails to teach these foundations does not merely omit an introductory topic; it omits the scientific basis upon which every subsequent quantitative claim depends.

THE CRITICAL ROLE OF RATIO SCALES

The analysis of New Zealand HTA programs must begin with the scientific principles that govern all quantitative inquiry. The first responsibility of any scientific discipline is to establish lawful measurement. Before numerical values can be manipulated, compared, multiplied, or divided, it must first be demonstrated that they represent measurable quantities. This principle has been accepted throughout the physical sciences and, since the development of representational measurement theory in the mid-twentieth century, has provided the scientific foundation for quantitative claims in the biological and social sciences. It is not arithmetic that defines science; it is measurement. Arithmetic is merely the language through which established measurements are analyzed and interpreted.

For health technology assessment, this distinction is fundamental. Every quantitative claim concerning therapy impact ultimately rests upon arithmetic operations. Cost-effectiveness analysis divides costs by measures of health benefit. Quality-adjusted life years multiply measures of health status by time. Decision models repeatedly multiply probabilities, transition rates, utilities, durations, and resource use. The validity of these calculations therefore depends entirely upon the validity of the measures entering them. If the underlying quantities are not lawful measures, no amount of statistical sophistication or computational complexity can transform the resulting calculations into scientifically meaningful evidence.

The critical issue is therefore the nature of the measurement scale. Representational measurement recognizes four broad classes of scale, nominal, ordinal, interval, and ratio but only one of these supports the full range of arithmetic operations required by quantitative science. A ratio measure is characterized by equal units of measurement together with a true, non-arbitrary zero representing the complete absence of the attribute being measured. Because equal differences represent equal quantities and ratios between observations are meaningful, all arithmetic operations, including multiplication and division, are admissible. Ratio measurement is therefore the necessary condition for quantitative analysis whenever products, ratios, averages, rates, or proportional comparisons are required.

This property distinguishes ratio scales from all other forms of measurement. Nominal scales merely classify observations. Ordinal scales rank observations without establishing equal distances between adjacent values. Interval scales possess equal intervals but lack a true zero, making ratios meaningless. Only ratio scales support statements such as "twice as much," "half as great," or "three times the quantity." Whenever multiplication or division is undertaken, the quantities involved must therefore be expressed on ratio scales. This is not a methodological preference but a mathematical necessity arising directly from the axioms of representational measurement.

The implications for health technology assessment are immediate. Contemporary HTA relies almost entirely upon multiplicative arithmetic. Quality-adjusted life years are calculated by multiplying a measure of health status by survival time. Incremental cost-effectiveness ratios divide differences in costs by differences in health outcomes. Decision-analytic models continually combine probabilities, transition rates, utilities, resource use, and durations through repeated multiplication and division. The entire analytical framework therefore presupposes that the quantities entering these calculations are ratio measures. Without ratio measurement, the arithmetic upon which HTA depends is inadmissible.

This requirement leads, as already noted, to a remarkably simple conclusion. There are only two admissible forms of ratio measurement applicable to claims for therapy impact. The first is the linear ratio measure, appropriate for manifest attributes that are directly observable. The second is the Rasch logit ratio measure, required for latent attributes that cannot be observed directly.

Once these two forms of ratio measurement are recognized, every subsequent methodological requirement follows naturally. Manifest attributes require linear ratio measures. Latent attributes require Rasch logit ratio measures. Arithmetic is admissible only when these measures have first been established. Dimensional homogeneity becomes a necessary condition for combining quantities. Multiplication and division become restricted to lawful ratio measures. Conversely, ordinal preference scores, utilities and other numerical constructions that fail to satisfy the requirements of ratio measurement cannot legitimately support multiplicative arithmetic, irrespective of how widely they are used or how sophisticated the subsequent modelling may appear.

This principle provides the single scientific criterion upon which Canadian HTA education should be judged. The question addressed in the present investigation is therefore straightforward. Do the five Canadian university programs that provide the country's principal teaching and research capacity in health economics and health technology assessment introduce students to ratio measurement as the indispensable foundation of quantitative analysis before presenting utilities, QALYs, cost-effectiveness analysis, simulation modelling and reimbursement frameworks? Or do they reverse this sequence by teaching computational methods without first establishing the scientific conditions that make those methods admissible?

The answer to this question is of more than academic interest. Canadian university programs provide the analytical framework that ultimately informs reimbursement submissions, health technology assessment and funding decisions undertaken by Canada's Drug Agency (CDA), the Institut national d'excellence en santé et en services sociaux (INESSS), provincial health technology assessment organizations and hospital-based assessment programs. If the educational programs preparing future HTA practitioners fail to recognize ratio measurement as the indispensable foundation of quantitative analysis, then the implications extend throughout Canadian HTA practice. Ratio measurement is therefore not simply one topic among many within measurement theory. This principle provides the single scientific criterion upon which any curriculum in health technology assessment should be judged

PROGRAM CONTENT AND COVERAGE

The assessment of program content and coverage employs the same methodological framework that has been used throughout this series of investigations to evaluate measurement inversion and curriculum inversion. In each case, the analytical instrument was the structured interrogation of artificial intelligence large language models (LLMs). The underlying principle remains unchanged. Rather than relying upon subjective interpretation of educational material, the LLM is used to interrogate a defined knowledge base against an explicit set of scientific criteria derived from the axioms of representational measurement together with the standards and constructs that characterize contemporary HTA.

In the previous investigations of measurement inversion and curriculum inversion, the interrogations were based upon a series of canonical statements representing either scientifically correct or scientifically incorrect propositions concerning measurement. Each statement was evaluated in terms of the extent to which it was endorsed by the institutional knowledge base. Endorsement was expressed as a canonical probability ranging from complete rejection to complete acceptance, with corresponding normalized logit values providing a common quantitative scale. The resulting endorsement profiles allowed direct comparison of institutions, agencies and educational programs, identifying the extent to which each knowledge base supported or rejected the scientific principles required for quantitative measurement.

The knowledge base interrogated in those earlier studies was defined broadly. It comprised the publicly accessible body of information associated with the institution under investigation, including research publications, methodological guidance, educational material, policy documents, technical reports, websites, teaching resources and other documentary evidence. The objective was to determine whether the institution, viewed as a whole, endorsed the principles of representational measurement or, alternatively, exhibited measurement inversion through the endorsement of numerical constructs that failed the requirements for lawful measurement.

The present assessment applies exactly the same interrogation methodology but with a more narrowly defined knowledge base. Rather than considering the complete institutional knowledge base, the focus is restricted to the educational programs offered by each research center. The knowledge base therefore comprises course descriptions, program outlines, syllabi where available, workshop descriptions, educational objectives, teaching modules, reading lists and other publicly available material describing the structure and content of the educational programs. The objective is not to evaluate institutional research activity or methodological publications but to determine what students are actually taught.

The interrogation is consequently more focused than those undertaken previously. Instead of examining the general endorsement of measurement principles across an institution, the analysis seeks to establish whether the educational content presented to students includes the scientific foundations required for quantitative measurement. The central question is whether representational measurement is taught before students are introduced to the numerical methods that characterize contemporary health technology assessment.

The assessment rests upon the presence or absence of educational content representing the accepted theory of measurement. The benchmark is provided by the ten essential topics that define the scientific foundations of HTA education. These encompass representational measurement, scales of measurement, the principle that measurement precedes arithmetic, the axioms of representational measurement, the distinction between manifest and latent attributes, linear ratio measurement for manifest attributes, Rasch logit ratio measurement for latent attributes, possession of latent attributes as the defining objective of Rasch measurement, admissible arithmetic and dimensional homogeneity, and the application of these principles in evaluating therapy claims. Collectively, these topics define the minimum scientific content that should precede instruction in health technology assessment methods.

These foundational topics are contrasted with the methods that dominate contemporary HTA. These include utilities and preference-based instruments, quality-adjusted life years (QALYs), cost-effectiveness analysis, incremental cost-effectiveness ratios, decision trees, Markov models, microsimulation, probabilistic sensitivity analysis, value-of-information analysis and related modelling techniques. The purpose is not to assess these methods as alternative analytical approaches that might become scientifically acceptable once representational measurement has been acknowledged; that would be impossible. Rather, the purpose is to determine whether the research program recognizes the scientific principles that govern quantitative inquiry. Once representational measurement is accepted, only two forms of ratio measurement are admissible for claims of therapy impact: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. Utilities, multiattribute preference scores and QALYs do not satisfy these requirements and therefore cannot support the arithmetic upon which contemporary HTA depends. The issue is consequently not whether representational measurement precedes these methods, but that acceptance of representational measurement excludes them as scientifically admissible quantitative procedures. The two frameworks are therefore fundamentally incompatible: one requires measurement before arithmetic, while the other substitutes arithmetic for measurement.

The distinction is critical. In the earlier investigations, endorsement probabilities demonstrated whether institutional knowledge bases accepted or rejected the principles of representational measurement. In the present investigation, the question is more direct: does the educational program teach these principles at all? If the scientific foundations of measurement are absent, while conventional HTA methods occupy the curriculum, the educational sequence has been inverted. Students are introduced to arithmetic, modelling and decision analysis before they are taught the conditions under which those procedures are scientifically admissible.

This progression from measurement inversion, to curriculum inversion, to program content inversion provides a coherent framework for evaluating HTA education. Measurement inversion identifies failure to recognize the scientific requirements for quantitative claims. Curriculum inversion demonstrates that these requirements are not embedded within educational programs.

Program content inversion identifies the immediate cause of that failure: the absence of explicit teaching of the scientific foundations of measurement within the programs themselves. It is this final level of analysis that forms the focus of the present investigation.

CONTENT AND COVERAGE ASSESSMENT FRAMEWORK

For the purposes of the content assessment, the educational knowledge base was defined more broadly than the brief program or course descriptions typically presented on institutional websites. Rather, the interrogation encompassed all publicly available material that defined the educational content of each program. This included program descriptions, learning objectives, curriculum outlines, lists of courses and modules, individual course descriptions, module summaries, syllabi where available, recommended reading lists, workshop and seminar descriptions, teaching resources, faculty descriptions of educational content, related educational webpages, and any supplementary material specifically associated with the educational program. Collectively, these sources provided the evidential basis for determining both the scope and the scientific content of the educational offerings available to prospective and current students.

The assessment was deliberately confined to educational material. It did not evaluate the broader research activities of the center, its publication record, methodological research, policy reports, or faculty scholarship unless these materials were explicitly incorporated into, or directly linked with, the educational program itself. The objective was not to determine what individual investigators might know or publish concerning measurement theory, but rather to establish what students are expected to learn through the formal educational activities offered by each center.

The first stage of the assessment focused exclusively on the scientific foundations of measurement. The question was not whether the educational material referred to measurement in a general or descriptive sense, but whether it explicitly presented the concepts required to support lawful quantitative analysis. Particular attention was given to the ten essential topics that define the minimum scientific content of an HTA curriculum: representational measurement, scales of measurement, the principle that measurement precedes arithmetic, the axioms of representational measurement, the distinction between manifest and latent attributes, linear ratio measurement for manifest attributes, Rasch logit ratio measurement for latent attributes, possession of latent attributes as the defining objective of Rasch measurement, admissible arithmetic and dimensional homogeneity, and the recognition that quantitative evaluation of therapy claims rests exclusively upon these two admissible forms of ratio measurement.

The second stage of the assessment examined the extent to which the programs covered the methods that characterize contemporary HTA. These included preference elicitation, multiattribute utility instruments, quality-adjusted life years, cost-effectiveness analysis, incremental cost-effectiveness ratios, decision trees, Markov models, microsimulation, probabilistic sensitivity analysis, value-of-information analysis, budget impact analysis, and related techniques that dominate present-day HTA practice.

The relationship between these two stages of the assessment is central to the present investigation. The issue is not whether contemporary HTA methods are taught as they are expected to be but whether they are taught only after students have acquired the scientific principles that determine when quantitative claims are permissible. If a curriculum provides comprehensive instruction in modelling, economic evaluation, and decision analysis while offering little or no instruction in representational measurement and ratio measurement, then the sequence required by quantitative science has been reversed. Arithmetic has displaced measurement as the foundation of analysis.

The resulting content profile therefore provides a direct assessment of program content inversion. Programs that teach the scientific requirements for lawful measurement before introducing HTA applications conform to the expected standards of quantitative science. Programs that omit these foundations while emphasizing utilities, QALYs, cost-effectiveness analysis, and simulation modelling exhibit program content inversion. It is this inversion that provides the immediate educational mechanism through which curriculum inversion and, ultimately, measurement inversion, are reproduced within health technology assessment.

The two components of the assessment are, by construction, mutually exclusive. Acceptance of the principles of representational measurement necessarily determines the admissibility of subsequent quantitative methods. A curriculum that explicitly teaches ratio measurement, the distinction between manifest and latent attributes, admissible arithmetic, dimensional homogeneity, and the two lawful forms of ratio measurement would have no scientific basis for treating ratio-free numerical constructions as quantitative measures. Once measurement precedes arithmetic is accepted as a foundational principle, the analytical methods subsequently taught must conform to those measurement requirements. The scientific foundations therefore determine, rather than merely accompany, the methods that follow.

Conversely, where there is no evidence that a curriculum recognizes the principles of representational measurement, no scientific constraints exist to prevent the adoption of the ratio-free analytical structures that characterize contemporary HTA. Utilities, multiattribute preference instruments, QALYs, incremental cost-effectiveness ratios, and reference-case simulation models can then be introduced without any prior consideration of whether the quantities involved satisfy the requirements for ratio measurement. The omission of representational measurement therefore provides the educational conditions under which these methods become accepted as legitimate analytical tools. Program content inversion is thus not simply the absence of one body of knowledge and the presence of another; it represents two fundamentally incompatible conceptions of quantitative science. One requires that arithmetic be constrained by lawful measurement. The other permits arithmetic to proceed independently of measurement, thereby institutionalizing measurement inversion within the educational program.

ASSESSMENT RESULTS

A separate assessment is presented for each of the seven research centers included in this investigation. Each assessment applies the common content and coverage framework described in the previous section and is based upon the publicly available educational materials defining the center's educational programs. The objective is to determine whether the scientific foundations of representational measurement are explicitly embedded within the educational content and whether these foundations precede instruction in analytical frameworks for HTA.

Each assessment is presented in a common format to facilitate direct comparison across centers. The first component examines evidence for the presence or absence of the essential principles of representational measurement, with particular emphasis on ratio measurement, the distinction between manifest and latent attributes, and the recognition that lawful quantitative claims require either linear ratio measures or Rasch logit ratio measures. The second component examines the extent to which the program emphasizes the conventional analytical methods of contemporary HTA, including utilities, QALYs, cost-effectiveness analysis, decision modelling, simulation methods, and related applications.

Because all centers are evaluated against the same scientific criteria, the resulting assessments provide a consistent basis for identifying similarities and differences in educational content. Of particular interest is whether the programs demonstrate the expected sequence in which measurement precedes arithmetic, or whether they exhibit program content inversion by emphasizing numerical methods in the absence of the scientific principles required to justify their application.

The individual assessments are followed by a comparative summary that identifies the common patterns across all seven centers and considers their implications for HTA education. Collectively, these findings provide the empirical basis for determining whether program content inversion represents isolated institutional variation or a systematic characteristic.

CURRICULUM CONTENT REVIEW

Institution

University of British Columbia

Centre

School of Population and Public Health
Health Economics Concentration
Centre for Health Evaluation and Outcome Sciences
Faculty of Pharmaceutical Sciences

Purpose

This review evaluates the publicly available curriculum associated with the University of British Columbia against a single scientific criterion: whether representational measurement is explicitly taught before students are introduced to the quantitative methods of health economics and health technology assessment. Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch measurement. These are the requirements that must be established before arithmetic operations can support valid quantitative claims concerning therapy impact.

Programs and Courses Reviewed

The review covers graduate and professional teaching in population and public health, health economics, health administration, pharmaceutical sciences and health outcomes research associated with the University of British Columbia.

Programs and curricula reviewed include:

- Master of Science in Population and Public Health: Health Economics Concentration
- Master of Public Health
- Master of Health Science
- Master of Health Administration
- Graduate programs in Pharmaceutical Sciences
- Bachelor of Pharmaceutical Sciences
- SPPH 514 Decision Analysis in Health Care
- SPPH 541 Economic Evaluation
- SPPH 546 Introduction to Health Economics
- SPPH 547 Health Care Priority Setting
- SPPH 549 Advanced Economic Evaluation in Health Care
- SPHA 531 Economic Evaluation
- SPHA 532 Health Economics
- SPHA 533 Health Care Priority Setting
- PHAR 422 Pharmacoeconomics

The MSc Health Economics concentration requires economic evaluation, health policy and health economics courses and offers decision analysis, priority setting and advanced economic evaluation as electives. The MPH curriculum also includes an economics and evaluation component, while the Master of Health Administration contains courses in economic evaluation, health economics and priority setting.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly taught	Course or program
Representational measurement	No evidence identified	—
Scales of measurement	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement	No evidence identified	—
True zero and equal units	No evidence identified	—
Admissible transformations	No evidence identified	—
Admissible arithmetic by scale type	No evidence identified	—
Dimensional homogeneity	No evidence identified	—
Manifest and latent attributes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Possession of latent attributes	No evidence identified	—

Rasch measurement	No evidence identified	—
Person–item conjoint measurement	No evidence identified	—
Specific objectivity and invariance	No evidence identified	—
Rasch logit ratio measurement for latent attributes	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

B. CONVENTIONAL HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly taught	Course or program
Health economics	Yes	SPPH 546; SPHA 532; MSc Health Economics Concentration
Health technology assessment	Yes	SPPH 549; PHAR 422
Economic evaluation	Yes	SPPH 541; SPPH 549; SPHA 531
Cost-effectiveness analysis	Yes	SPPH 541; SPHA 531
Pharmacoeconomics	Yes	PHAR 422
Decision analysis	Yes	SPPH 514
Health care priority setting	Yes	SPPH 547; SPHA 533
Resource allocation	Yes	SPPH 541; SPPH 547; SPHA 531
Value-for-money assessment	Yes	SPPH 541; SPHA 531
Policy use of economic evaluation	Yes	SPPH 549
Evaluation of health technologies	Yes	SPPH 549; PHAR 422
Measurement and valuation of health outcomes	Research emphasis identified	Pharmaceutical Sciences and affiliated health-outcomes research
Utilities and preference-based outcomes	No explicit course-level evidence identified in the public descriptions reviewed	—
Quality-adjusted life-years	No explicit course-level evidence identified in the public descriptions reviewed	—
Incremental cost-effectiveness ratios	No explicit course-level evidence identified in the public descriptions reviewed	—

Decision-tree modelling	No explicit course-level evidence identified in the public descriptions reviewed	—
Markov modelling	No explicit course-level evidence identified in the public descriptions reviewed	—
Probabilistic sensitivity analysis	No explicit course-level evidence identified in the public descriptions reviewed	—
Value-of-information analysis	No explicit course-level evidence identified in the public descriptions reviewed	—

UBC describes SPPH 541 as teaching the principles and methods of economic evaluation with an emphasis on cost-effectiveness and value for money. SPPH 549 provides practical instruction in evaluating health technologies and considers the policy use of economic evaluation. SPHA 531 applies cost-effectiveness analysis to resource-allocation decisions, while PHAR 422 addresses health economics, economic evaluation and HTA studies.

Assessment

The University of British Columbia provides one of Canada's most extensive and clearly identifiable university-based educational frameworks in health economics, economic evaluation and health technology assessment. Its School of Population and Public Health offers a formal MSc Health Economics concentration supported by required courses in economic evaluation, health economics and health policy, together with electives in decision analysis, priority setting and advanced economic evaluation. Related instruction is embedded within the MPH, Master of Health Science and Master of Health Administration programs. The Faculty of Pharmaceutical Sciences also offers instruction in pharmacoeconomics and HTA and supports graduate research in pharmaceutical health outcomes.

This breadth of teaching makes UBC an important contributor to the Canadian HTA knowledge base. Students are trained to undertake economic evaluation, assess cost-effectiveness, apply decision analysis, evaluate health technologies and contribute to priority-setting and resource-allocation decisions. The curriculum therefore provides substantial preparation in the numerical and analytical methods that characterize contemporary HTA.

Against the single scientific criterion applied in this review, however, the curriculum fails. No evidence was identified in the publicly available program and course descriptions that students are first introduced to representational measurement as the necessary foundation for quantitative analysis. There is no explicit recognition that measurement must precede arithmetic, that the admissibility of mathematical operations is determined by scale properties, or that multiplication and division require ratio measurement. There is likewise no identifiable instruction in admissible transformations, dimensional homogeneity or the axioms that must be satisfied before numbers can support quantitative claims.

The distinction between manifest and latent attributes is also absent. No curriculum requirement was identified that manifest therapy attributes must be represented by linear ratio measures or that latent attributes require Rasch logit ratio measurement. Rasch measurement, person–item conjoint measurement, specific objectivity, invariance and the measurement of individual possession of a latent attribute do not appear as foundations of the educational framework.

The result is program content inversion. UBC teaches students how to perform economic evaluation and HTA before establishing whether the numbers entering those analyses possess the properties required for lawful arithmetic. Cost-effectiveness analysis, value-for-money assessment, decision analysis and health technology evaluation are presented as established quantitative methods, while the prior scientific question—whether the relevant attributes have been measured on admissible ratio scales—is not addressed.

This omission cannot be treated as the absence of one optional methodological topic. Ratio measurement is the single criterion governing whether the arithmetic operations used in HTA are scientifically admissible. Once that standard is applied, there are only two acceptable measures for claims concerning therapy impact: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. No evidence was identified that either requirement structures the UBC curriculum.

The publicly available UBC educational framework therefore teaches students to apply arithmetic to numerical constructions without first demonstrating that those constructions are lawful measures. The sophistication and breadth of the subsequent analysis cannot correct this foundational failure. Statistical methods, economic models and decision frameworks cannot create measurement where measurement has not first been established.

On the evidence reviewed, the University of British Columbia curriculum does not satisfy the accepted scientific standards required for quantitative measurement. It reproduces the conventional Canadian HTA framework without subjecting that framework to the prior requirements of representational measurement. The curriculum must therefore be regarded as scientifically invalid for claims concerning quantitative therapy impact.

Correction requires curriculum reconstruction rather than the addition of a supplementary lecture on measurement. Representational measurement must become the foundation of the program. Students must first be taught that measurement precedes arithmetic; that quantitative claims require ratio measurement; that manifest and latent attributes demand different measurement procedures; and that only linear ratio measures and Rasch logit ratio measures can support the full arithmetic operations required for therapy-impact claims. Only after these principles have been established should students proceed to economic evaluation, cost-effectiveness analysis, decision modelling, health technology assessment and resource allocation.

CURRICULUM CONTENT REVIEW

Institution

University of Alberta

Centre

School of Public Health
Graduate Embedded Certificate in Health Economic Evaluation

Purpose

This review evaluates the publicly available curriculum associated with the University of Alberta against a single scientific criterion: whether representational measurement is explicitly taught before students are introduced to the quantitative methods of health economics and health technology assessment. Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch measurement. These are the requirements that must be established before arithmetic operations can support valid quantitative claims concerning therapy impact.

Programs and Courses Reviewed

The review covers graduate teaching in public health, health economics, health economic evaluation, health technology assessment and health-related quality-of-life assessment associated principally with the School of Public Health.

Programs and curricula reviewed include:

Graduate Embedded Certificate in Health Economic Evaluation
Master of Public Health
Graduate programs in public health
SPH 570 Introduction to Health Economics
SPH 671 Introduction to Health Economic Evaluation
SPH 672 Advanced Health Economic Evaluations
SPH 673 Technology Assessment for Health Care
SPH 685 Methods for the Assessment of Health-Related Quality of Life
ECON 357 Health Economics

The Graduate Embedded Certificate in Health Economic Evaluation is supported by a particularly clear sequence of courses. SPH 570 introduces health-economic theory, resource allocation and economic evaluation. SPH 671 covers cost-effectiveness and cost-utility analysis, measuring and valuing health, uncertainty, probabilistic analysis and basic decision-analytic modelling. SPH 672 extends this framework to value-of-information analysis, distributional cost-effectiveness analysis, opportunity-cost measurement and advanced modelling.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly taught	Course or program
Representational measurement	No evidence identified	—
Scales of measurement	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement	No evidence identified	—
True zero and equal units	No evidence identified	—
Admissible transformations	No evidence identified	—
Admissible arithmetic by scale type	No evidence identified	—
Dimensional homogeneity	No evidence identified	—
Manifest and latent attributes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Possession of latent attributes	No evidence identified	—
Rasch measurement	No evidence identified	—
Person–item conjoint measurement	No evidence identified	—
Specific objectivity and invariance	No evidence identified	—
Rasch logit ratio measurement for latent attributes	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

B. CONVENTIONAL HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly taught	Course or program
Health economics	Yes	SPH 570; ECON 357
Health economic evaluation	Yes	SPH 570; SPH 671; SPH 672
Health technology assessment	Yes	SPH 673
Cost-effectiveness analysis	Yes	SPH 671; SPH 672
Cost-utility analysis	Yes	SPH 671
Measuring and valuing health	Yes	SPH 671; SPH 672
Resource-use and cost assessment	Yes	SPH 671
Discounting	Yes	SPH 671; SPH 672

Decision-analytic modelling	Yes	SPH 671; SPH 672
Probabilistic analysis	Yes	SPH 671; SPH 672
Value-of-information analysis	Yes	SPH 672
Distributional cost-effectiveness analysis	Yes	SPH 672
Opportunity-cost measurement	Yes	SPH 672
Social choice	Yes	SPH 672
Health-care resource allocation	Yes	SPH 570; ECON 357
Policy application of HTA	Yes	SPH 673
Health-related quality-of-life assessment	Yes, in catalogue; not currently scheduled	SPH 685
Psychometric assessment of HRQL instruments	Yes, in catalogue; not currently scheduled	SPH 685
Reliability, validity and responsiveness	Yes, in catalogue; not currently scheduled	SPH 685
Utilities and preference-based health outcomes	Implicit in cost-utility and health-valuation teaching; not separately identified in public descriptions	SPH 671; SPH 672
Quality-adjusted life-years	No explicit course-level reference identified in the public descriptions reviewed	—
Incremental cost-effectiveness ratios	No explicit course-level reference identified in the public descriptions reviewed	—
Markov modelling	No explicit course-level reference identified in the public descriptions reviewed	—

SPH 673 explicitly presents HTA as a field concerned with the methods used to assess health technologies and the application of findings to policy and administrative decisions. It emphasizes assessments undertaken by national and regional agencies in Canada and elsewhere.

SPH 685 is especially relevant because its stated objective is to prepare students to use and interpret health-related quality-of-life measures. Its topics include the classification of HRQL instruments, reliability, validity, responsiveness, interpretability and psychometric, clinical, economic and decision-analytic approaches to instrument development. The public catalogue indicates, however, that the course has no currently scheduled offering.

Assessment

The University of Alberta provides one of the most explicit and methodologically developed university-based curricula in health economic evaluation in Canada. Unlike programs in which health economics appears only as an elective or as one component of a broader public-health degree, Alberta offers a formal Graduate Embedded Certificate in Health Economic Evaluation. Its educational sequence extends from introductory health economics through basic and advanced economic evaluation, decision-analytic modelling, probabilistic analysis, value-of-information analysis and health technology assessment.

This breadth makes Alberta a particularly important case for assessing the scientific foundations of Canadian HTA education. Students are not merely introduced to general economic principles. They are taught how to undertake cost-effectiveness and cost-utility analysis, measure and value health outcomes, estimate resource use and costs, manage uncertainty, construct decision-analytic models and apply HTA findings to policy decisions. Advanced students are introduced to distributional cost-effectiveness analysis, social choice, opportunity cost and complex modelling methods.

Against the single scientific criterion applied in this review, however, the curriculum fails. No evidence was identified in the publicly available course and program descriptions that students are first introduced to representational measurement as the foundation for quantitative analysis. There is no explicit requirement that measurement must precede arithmetic, that mathematical operations are governed by the properties of the measurement scale, or that multiplication and division require ratio measurement.

There is likewise no identifiable teaching of the axioms of representational measurement, admissible transformations or dimensional homogeneity. Students are taught to combine costs, health outcomes, probabilities, time, preferences and model parameters without first being required to demonstrate that the quantities entering these operations possess the properties necessary to support the arithmetic employed.

The absence of a distinction between manifest and latent attributes is particularly important. Resource use, duration of treatment, hospital admissions and other directly observable attributes require linear ratio measures. Pain, fatigue, physical functioning, anxiety, quality of life and related patient-reported attributes are latent and require a different measurement procedure. Yet no evidence was identified that the curriculum requires linear ratio measurement for manifest attributes or Rasch logit ratio measurement for latent attributes.

The presence of SPH 685 does not resolve this failure. The course catalogue refers to reliability, validity, responsiveness, interpretability and psychometric approaches to health-related quality-of-life instruments. These are conventional instrument-assessment criteria. They do not establish that a latent attribute has been represented on an invariant quantitative continuum, nor do they demonstrate individual possession of the attribute through Rasch person–item conjoint measurement. No explicit role is assigned to Rasch measurement, specific objectivity, invariant item calibration or the construction of a Rasch logit ratio measure.

The result is program content inversion. Alberta begins with health economics and proceeds through cost-effectiveness, cost-utility analysis, health valuation, probabilistic analysis and advanced modelling without first establishing whether the numerical inputs are lawful measures. Arithmetic and modelling therefore precede measurement.

This failure is especially clear in SPH 671. The course combines cost-utility analysis, measuring and valuing health, discounting, uncertainty and decision modelling within a single methodological framework. Yet the publicly available description contains no prior requirement that the health attribute be unidimensional, that its numerical representation satisfy the axioms of measurement, or that the resulting values support multiplication, division and proportional comparison.

SPH 672 deepens rather than resolves the problem. Advanced probabilistic analysis, value-of-information analysis, distributional cost-effectiveness analysis and complex modelling add further layers of arithmetic, but greater mathematical sophistication cannot compensate for the absence of measurement. A complex model constructed from quantities that are not lawful measures remains a numerical construction.

The central issue is not whether Alberta teaches contemporary health economic evaluation competently according to accepted Canadian practice. The course descriptions make clear that this is precisely what the program intends to do. The issue is that prevailing Canadian practice itself proceeds without first satisfying the scientific requirements of representational measurement. Teaching students "current best practices" cannot establish scientific validity where the measurement properties required to support those practices have not been demonstrated.

Ratio measurement provides the single criterion by which the curriculum must therefore be judged. Claims concerning therapy impact can be supported by only two lawful forms of measurement: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. No evidence was identified that this distinction structures the Alberta curriculum or constrains the arithmetic and modelling methods taught.

On the publicly available evidence, the University of Alberta curriculum does not satisfy the scientific standards required for quantitative measurement. It provides extensive training in economic evaluation and HTA while omitting the prior conditions that determine whether quantitative analysis is permissible. The curriculum must therefore be regarded as scientifically invalid for claims concerning quantitative therapy impact.

Correction requires curriculum reconstruction rather than marginal revision. Representational measurement must precede health economics, cost-effectiveness analysis and decision modelling. Students must first learn how attributes are defined, how lawful measures are constructed, why arithmetic is restricted by scale type, why dimensional homogeneity is mandatory and why manifest and latent attributes require different ratio measures. Only after these foundations have been established should instruction proceed to the evaluation of therapies, health technologies and resource-allocation decisions.

CURRICULUM CONTENT REVIEW

Institution

McMaster University

Centre

Department of Health Research Methods, Evidence, and Impact
Health Research Methodology Program
Health Economics at McMaster
Centre for Health Economics and Policy Analysis

Purpose

This review evaluates the publicly available curriculum associated with McMaster University against a single scientific criterion: whether representational measurement is explicitly taught before students are introduced to the quantitative methods of health economics and health technology assessment. Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch measurement. These are the requirements that must be established before arithmetic operations can support valid quantitative claims concerning therapy impact.

Programs and Courses Reviewed

The review covers graduate and undergraduate teaching in health research methodology, health technology assessment, health economics, economic evaluation and health policy associated with McMaster University.

Programs and curricula reviewed include:

- Master of Science in Health Research Methodology: Health Technology Assessment
- Doctor of Philosophy in Health Research Methodology: Health Technology Assessment
- Master of Arts in Economic Policy: Health Economics Concentration
- Master of Arts in Economics: Health Economics Concentration
- Doctor of Philosophy in Economics: Health Economics Field
- Doctor of Philosophy in Health Policy: Health Economics Field
- Master of Public Health
- Programs for Assessment of Technology in Health workshops
- HRM 740 Advanced Decision Analysis in Health Technology Assessment
- Graduate health economics courses
- ECON 793 Health Economic Policy
- ECON 795 Analysis of Health Data
- ECON 2CC3 Health Economics and its Application to Health Policy
- HTH 501 Fundamentals of Health Research Methodology

McMaster’s Health Research Methodology program offers MSc and PhD training with health technology assessment identified as a formal area of specialization. Health Economics at McMaster also lists multiple graduate pathways in health economics and health policy, together with dedicated HTA workshops and advanced methodological courses.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly taught	Course or program
Representational measurement	No evidence identified	—
Scales of measurement	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement	No evidence identified	—
True zero and equal units	No evidence identified	—
Admissible transformations	No evidence identified	—
Admissible arithmetic by scale type	No evidence identified	—
Dimensional homogeneity	No evidence identified	—
Manifest and latent attributes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Possession of latent attributes	No evidence identified	—
Rasch measurement	No evidence identified	—
Person–item conjoint measurement	No evidence identified	—
Specific objectivity and invariance	No evidence identified	—
Rasch logit ratio measurement for latent attributes	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

B. CONVENTIONAL HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly taught	Course or program
Health economics	Yes	Graduate health economics programs; ECON 2CC3; ECON 793
Health technology assessment	Yes	MSc and PhD Health Research Methodology specializations; HRM 740
Economic evaluation	Yes	HRM 740; health economics programs
Decision analysis	Yes	HRM 740
Cost-effectiveness analysis	Yes, within economic evaluation framework	HRM 740 and HTA specialization

Systematic literature review	Yes	HRM 740
Analysis of uncertainty	Yes	HRM 740
Value-of-information analysis	Yes	HRM 740
Bayesian decision analysis	Yes	HRM 740
Budget impact analysis	Yes	HRM 740
Quality assurance in economic appraisal	Yes	HRM 740
HTA agency guidelines and requirements	Yes	HRM 740
Government decision-making frameworks	Yes	HRM 740
Knowledge translation	Yes	HRM 740; HTH 501
Health policy analysis	Yes	ECON 793; graduate health economics programs
Health-data analysis	Yes	ECON 795
Health-care financing and funding	Yes	ECON 793; health economics programs
Economics of the pharmaceutical sector	Yes, as a possible topic	ECON 793
Research design and critical appraisal	Yes	Health Research Methodology program; HTH 501
Outcome measurement	Yes, general reference	HTH 501
Utilities and preference-based health outcomes	No explicit course-level evidence identified in public descriptions reviewed	—
Quality-adjusted life-years	No explicit course-level evidence identified in public descriptions reviewed	—
Incremental cost-effectiveness ratios	No explicit course-level evidence identified in public descriptions reviewed	—
Markov modelling	No explicit course-level evidence identified in public descriptions reviewed	—
Probabilistic sensitivity analysis	Analysis of uncertainty identified; specific method not stated	HRM 740
Multiattribute utility instruments	No explicit course-level evidence identified	—

Rasch analysis of patient-reported outcomes	No evidence identified	—

HRM 740 is described as an advanced theoretical and practical course in health technology assessment. It teaches systematic literature review, economic evaluation, uncertainty analysis, value-of-information analysis, Bayesian decision analysis, quality assurance in economic appraisal, budget impact analysis and knowledge translation. Students are also exposed to national and international HTA agencies and their guidelines and requirements. The course places substantial emphasis on computer-based application using practical examples.

Assessment

McMaster University occupies a distinctive position in Canadian health technology assessment. It does not merely offer individual courses in health economics or economic evaluation. Its Health Research Methodology program provides formal MSc and PhD specialization in health technology assessment, while Health Economics at McMaster coordinates educational opportunities extending from undergraduate health economics to graduate degrees, doctoral fields, HTA workshops and advanced decision analysis.

McMaster therefore represents one of the clearest possible tests of whether Canadian HTA education recognizes the scientific requirements that must precede quantitative analysis. Students are prepared to develop evaluation strategies, undertake health technology assessments, conduct economic evaluations, analyze uncertainty, construct decision frameworks and contribute to policy decisions. The university describes its health research methodology programs as preparing graduates to develop rigorous and innovative evaluation strategies capable of improving clinical practice, strengthening health systems and enhancing population health.

Against the single scientific criterion applied in this review, however, the curriculum fails. No evidence was identified in the publicly available program and course descriptions that representational measurement is taught as the necessary foundation for quantitative inquiry. There is no explicit recognition that measurement must precede arithmetic or that the admissibility of mathematical operations depends upon the properties of the measurement scale.

There is similarly no identifiable instruction in the axioms of representational measurement, admissible transformations, dimensional homogeneity or the unique role of ratio measurement in supporting multiplication, division and proportional comparison. Students may be taught how to perform advanced quantitative analyses, but the publicly available curriculum provides no evidence that they are first taught how to determine whether the numerical values entering those analyses are lawful measures.

This absence is especially significant in HRM 740. The course is described as teaching the essential components of contemporary HTA and includes economic evaluation, uncertainty analysis, value-of-information analysis, Bayesian decision analysis and budget impact analysis. Each of these methods depends upon extensive arithmetic operations involving health outcomes, probabilities, time, resource use and costs. Yet no publicly identified prerequisite requires students to demonstrate that the relevant therapy attributes possess ratio-scale properties before those operations are undertaken.

The curriculum therefore begins with the methods of contemporary HTA rather than the scientific conditions required to validate them. Students learn how HTA agencies construct and apply evaluation frameworks, how economic models are developed, how uncertainty is propagated and how findings are translated into policy. They are not first required to establish that the quantities entering those frameworks satisfy the axioms required for quantitative representation.

The general reference to outcome measurement in HTH 501 does not resolve this failure. The course presents outcome measurement within a broad introduction to research design, clinical trials, observational studies, systematic reviews, statistics and critical appraisal. No evidence was identified that outcome measurement is grounded in representational measurement, ratio scales, admissible transformations or the distinction between manifest and latent attributes.

The distinction between manifest and latent attributes is absent from the publicly available curriculum. Manifest attributes such as hospital days, treatment duration, doses administered and resource units require linear ratio measures. Latent attributes such as pain, fatigue, functioning, anxiety and need fulfilment cannot be observed directly and require Rasch logit ratio measurement. No evidence was identified that students are taught this distinction or that therapy-impact claims must be supported by one of these two lawful forms of measurement.

Rasch measurement is likewise absent. No curriculum requirement was identified for unidimensional latent attributes, person–item conjoint measurement, specific objectivity, invariant calibration or the measurement of individual possession of an attribute. Conventional outcome measurement, statistical modelling and parameter estimation cannot substitute for these requirements. A numerical score or estimated parameter does not become a measure merely because it is generated by a sophisticated statistical model.

The result is program content inversion. McMaster teaches increasingly advanced forms of HTA arithmetic without first establishing lawful measurement. Economic evaluation is followed by uncertainty analysis; uncertainty analysis is extended into value-of-information analysis; decision analysis is expanded through Bayesian methods; and the resulting outputs are applied to policy and reimbursement decisions. At no publicly identifiable point is the prior question resolved: are the quantities entering these operations ratio measures that support the arithmetic being performed?

The course emphasis on the guidelines and requirements of existing HTA agencies reinforces rather than corrects this problem. Agency acceptance does not establish scientific validity. If the agencies themselves accept utilities, QALYs and reference-case models without demonstrating lawful ratio measurement, teaching students to comply with those agency requirements reproduces the failure rather than subjects it to scientific evaluation.

McMaster's reputation for methodological innovation does not alter this conclusion. The issue is not whether its programs are technically advanced according to the conventions of contemporary HTA. The issue is whether those conventions satisfy the long-established requirements of representational measurement. Sophisticated modelling cannot compensate for the absence of a lawful measure. Bayesian analysis, uncertainty analysis, value-of-information analysis and computer simulation remain arithmetic operations performed upon their numerical inputs. Their scientific meaning depends entirely upon whether those inputs represent measurable quantities.

Ratio measurement therefore provides the sole criterion by which the McMaster curriculum must be judged. For claims concerning therapy impact, there are only two admissible forms of measurement: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. No evidence was identified that this requirement structures the Health Research Methodology curriculum, the HTA specialization or the advanced decision-analysis course.

On the publicly available evidence, McMaster University's HTA curriculum does not satisfy the accepted scientific standards required for quantitative measurement. It provides extensive and advanced training in the methods of contemporary health technology assessment while omitting the prior measurement conditions that determine whether those methods can generate valid quantitative claims. The curriculum must therefore be regarded as scientifically invalid for the quantitative assessment of therapy impact.

Correction requires fundamental reconstruction. Representational measurement must become the first requirement of the Health Research Methodology and HTA programs. Students must learn that measurement precedes arithmetic, that arithmetic is constrained by scale type, that dimensional homogeneity is mandatory and that manifest and latent attributes require different forms of ratio measurement. Only after lawful measures have been established should students proceed to economic evaluation, uncertainty analysis, decision modelling, value-of-information analysis, budget impact analysis and policy application.

McMaster may be the most important Canadian case because it formally claims to train specialists in HTA methodology rather than merely offering health economics as one component of a broader degree.

CURRICULUM CONTENT REVIEW

Institution

University of Toronto

Centre

Institute of Health Policy, Management and Evaluation (IHPME)
Dalla Lana School of Public Health

Purpose

This review evaluates the publicly available curriculum associated with the University of Toronto against a single scientific criterion: whether representational measurement is explicitly taught before students are introduced to the quantitative methods of health economics and health technology assessment. Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch measurement. These are the requirements that must be established before arithmetic operations can support valid quantitative claims concerning therapy impact.

Programs and Courses Reviewed

The review covers graduate teaching in health systems research, health economics, health technology assessment, outcomes evaluation and health policy within the Institute of Health Policy, Management and Evaluation.

Programs and curricula reviewed include:

- MSc Health Policy, Management and Evaluation
- MSc Health Systems Research
- PhD Health Policy, Management and Evaluation
- Health Technology Assessment emphasis
- Health Economics emphasis
- Outcomes and Evaluation Studies emphasis
- HAD 5011 Foundations in Health Systems Research
- HAD 5720 Evaluation I
- HAD 5730 Economic Evaluation Methods for Health Services Research
- HAD 5743 Evaluation II
- HAD 5760 Advanced Health Economics and Policy Analysis
- HAD 6750 Advanced Health Economics and Policy Analysis II
- HAD 5728 Performance Measurement in Healthcare
- HAD 5744 Quantitative Methods in Health Systems Research I
- HAD 5746 Quantitative Methods in Health Systems Research II

The MSc Health Systems Research program allows students to select formal emphases in Health Economics, Health Technology Assessment, Health Policy and Outcomes and Evaluation Studies. Required and elective courses include economic evaluation, evaluation methods, advanced health economics, quantitative methods and performance measurement.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly taught	Course or program
Representational measurement	No evidence identified	—
Scales of measurement	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement	No evidence identified	—
True zero and equal units	No evidence identified	—
Admissible transformations	No evidence identified	—

Admissible arithmetic by scale type	No evidence identified	—
Dimensional homogeneity	No evidence identified	—
Manifest and latent attributes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Possession of latent attributes	No evidence identified	—
Rasch measurement	No evidence identified	—
Person–item conjoint measurement	No evidence identified	—
Specific objectivity and invariance	No evidence identified	—
Rasch logit ratio measurement for latent attributes	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

B. CONVENTIONAL HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly taught	Course or program
Health economics	Yes	Health Economics emphasis; HAD 5760; HAD 6750
Health technology assessment	Yes	HTA emphasis
Economic evaluation	Yes	HAD 5730
Evaluation methods	Yes	HAD 5720; HAD 5743
Advanced health economics	Yes	HAD 5760; HAD 6750
Quantitative methods	Yes	HAD 5744; HAD 5746
Performance measurement	Yes	HAD 5728
Outcomes and evaluation studies	Yes	Outcomes and Evaluation Studies emphasis
Research design	Yes	HAD 5011
Health policy analysis	Yes	HAD 5760
Health systems research	Yes	MSc Health Systems Research
Evidence synthesis	Yes	HTA emphasis
Economic evaluation of technologies	Yes	HTA emphasis
Social, ethical and legal aspects of HTA	Yes	HTA emphasis
Utilities and preference-based outcomes	No explicit course-level evidence identified	—
Quality-adjusted life-years	No explicit course-level evidence identified	—
Incremental cost-effectiveness ratios	No explicit course-level evidence identified	—

Decision modelling	No explicit course-level evidence identified	—
Markov modelling	No explicit course-level evidence identified	—
Rasch analysis	No evidence identified	—

The University of Toronto describes HTA as an interdisciplinary field applying theories, concepts and methods to inform decisions concerning the introduction and use of health technologies. The Health Technology Assessment emphasis includes evidence synthesis, economic evaluation and the social, legal and ethical consequences of emerging technologies. Students in the Health Economics emphasis complete formal coursework in economic evaluation methods and advanced health economics.

Assessment

The University of Toronto offers one of Canada's most comprehensive academic programs in health policy, health economics and health technology assessment. Through the Institute of Health Policy, Management and Evaluation, students may pursue formal emphases in Health Technology Assessment, Health Economics and Outcomes and Evaluation Studies, supported by dedicated graduate courses in economic evaluation, evaluation methodology, quantitative methods and advanced health economics.

This breadth of instruction places Toronto among the leading Canadian centers responsible for educating future HTA researchers, policy analysts and health economists. Students are introduced to economic evaluation, quantitative analysis, performance measurement, evidence synthesis and the assessment of emerging health technologies. These are presented as the methodological foundations of contemporary HTA.

Against the single scientific criterion applied in this review, however, the curriculum fails. No evidence was identified in the publicly available curriculum that representational measurement is established as the prerequisite for quantitative analysis. Students are introduced to evaluation methods, economic evaluation and quantitative analysis without first being taught that measurement must precede arithmetic or that the admissibility of arithmetic operations depends upon the properties of the measurement scale.

No evidence was identified that students are instructed in the axioms of representational measurement, ratio measurement, admissible transformations or dimensional homogeneity. Likewise, no identifiable curriculum distinguishes between manifest attributes requiring linear ratio measurement and latent attributes requiring Rasch logit ratio measurement. Rasch measurement, specific objectivity, invariant person–item calibration and the measurement of individual possession of latent attributes do not appear within the publicly available educational framework.

This omission is particularly important because the curriculum explicitly prepares students for health technology assessment. The HTA emphasis identifies evidence synthesis, economic evaluation and health policy analysis as its principal methodological components. Yet no evidence was identified that students are first required to establish whether the health attributes entering these analyses possess the measurement properties necessary to support the arithmetic subsequently applied.

The presence of courses in Evaluation I, Evaluation II, Performance Measurement and Quantitative Methods do not resolve this deficiency. Evaluation methodology, statistical analysis and performance indicators are not substitutes for lawful quantitative measurement. Statistical sophistication cannot compensate for the absence of admissible measurement. Before arithmetic can be performed, the quantities entering those calculations must themselves be lawful measures.

The curriculum therefore reproduces the conventional Canadian HTA framework. Students are taught how to evaluate interventions, compare alternatives, undertake economic evaluations and inform policy decisions without first establishing whether the numerical quantities entering those analyses satisfy the requirements of representational measurement.

The scientific criterion is straightforward. There are only two admissible ratio measures for claims concerning therapy impact: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. No evidence was identified that either requirement forms part of the University of Toronto curriculum or constrains the methods taught within its Health Economics or Health Technology Assessment emphases.

On the publicly available evidence, the University of Toronto curriculum does not satisfy the accepted scientific standards required for quantitative measurement. It provides extensive education in the techniques of health economics and HTA while omitting the prior conditions that determine whether quantitative claims are scientifically permissible. The curriculum must therefore be regarded as scientifically invalid for claims concerning quantitative therapy impact.

Correction requires reconstruction rather than incremental revision. Representational measurement must become the foundation of the curriculum. Students must first learn that measurement precedes arithmetic, that arithmetic is constrained by scale type, that dimensional homogeneity is mandatory and that manifest and latent attributes require different forms of ratio measurement. Only after these principles have been established should instruction proceed to economic evaluation, health technology assessment, performance measurement and health policy analysis.

CURRICULUM CONTENT REVIEW

Institution

Université de Montréal

Centre

École de santé publique de l'Université de Montréal (ESPUM)

Purpose

This review evaluates the publicly available curriculum associated with the Université de Montréal against a single scientific criterion: whether representational measurement is explicitly taught before students are introduced to the quantitative methods of health economics and health technology assessment. Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch measurement. These are the requirements that must be established before arithmetic operations can support valid quantitative claims concerning therapy impact.

Programs and Courses Reviewed

The review covers graduate teaching in health technology assessment, health economics, evaluation science, epidemiology and public health within the École de santé publique.

Programs and curricula reviewed include:

- Maîtrise en évaluation des technologies de la santé (M.Sc.)
- DESS en évaluation des technologies de la santé
- Microprogramme en évaluation des technologies de la santé
- ASA 6175 Méthodes d'évaluation économique
- ASA 6178 Méthodes d'évaluation
- ASA 6732 Évaluation des technologies de la santé
- ASA 6177 Méthodologie de la recherche
- MSO 6008 Revues narratives et systématiques
- MSO 6011 Concepts et méthodes en épidémiologie
- MSO 6061 Introduction à la biostatistique
- MSO 6075 Essais cliniques randomisés

The Master's program provides specialized graduate education in health technology assessment through two streams—evaluation producer and evaluation user. The required curriculum includes economic evaluation, evaluation methods, HTA, epidemiology, biostatistics, systematic reviews and research methodology. The DESS and Microprogram provide shorter professional pathways built around the same methodological framework.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly taught	Course or program
Representational measurement	No evidence identified	—
Scales of measurement	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement	No evidence identified	—
True zero and equal units	No evidence identified	—
Admissible transformations	No evidence identified	—
Admissible arithmetic by scale type	No evidence identified	—

Dimensional homogeneity	No evidence identified —
Manifest and latent attributes	No evidence identified —
Linear ratio measurement for manifest attributes	No evidence identified —
Possession of latent attributes	No evidence identified —
Rasch measurement	No evidence identified —
Person-item conjoint measurement	No evidence identified —
Specific objectivity and invariance	No evidence identified —
Rasch logit ratio measurement for latent attributes	No evidence identified —
Two admissible ratio measures for therapy impact	No evidence identified —

B. CONVENTIONAL HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly taught	Course or program
Health technology assessment	Yes	ASA 6732; MSc HTA; DESS HTA
Economic evaluation	Yes	ASA 6175
Cost-effectiveness analysis	Yes	ASA 6175
Cost-utility analysis	Yes	ASA 6175
Cost-benefit analysis	Yes	ASA 6175
Evaluation methodology	Yes	ASA 6178
Systematic reviews	Yes	MSO 6008
Epidemiology	Yes	MSO 6011
Biostatistics	Yes	MSO 6061
Clinical trials	Yes	MSO 6075
Research methodology	Yes	ASA 6177
Health policy applications	Yes	ASA 6732
Assessment of effectiveness and safety	Yes	ASA 6732
Assessment of legal, ethical and social issues	Yes	ASA 6732
Technology acquisition and reimbursement	Yes	ASA 6732
Utilities and preference-based outcomes	No explicit course-level evidence identified	—
Quality-adjusted life-years	No explicit course-level evidence identified	—
Incremental cost-effectiveness ratios	No explicit course-level evidence identified	—
Decision modelling	No explicit course-level evidence identified	—

Markov modelling	No explicit course-level evidence identified	—
Rasch analysis	No evidence identified	—

ASA 6175 explicitly teaches the methods and limitations of economic evaluation, including cost-effectiveness, cost-utility and cost-benefit analysis. ASA 6732 introduces students to the concepts, methods and tools of health technology assessment and their application to decisions regarding technology acquisition, reimbursement and diffusion. The program also requires formal instruction in systematic reviews, epidemiology, biostatistics and randomized clinical trials.

Assessment

The Université de Montréal offers Canada's most explicit university program devoted entirely to health technology assessment. Rather than presenting HTA as one option within a broader health economics or public health curriculum, the École de santé publique has established dedicated Master's, DESS and Microprogramme pathways in health technology assessment. The stated objective is to prepare graduates to evaluate the effectiveness, safety, costs and social, ethical and legal dimensions of health technologies and to contribute directly to decisions concerning acquisition, reimbursement and diffusion.

This dedicated structure makes the Université de Montréal an especially important case for curriculum assessment. Students receive systematic instruction in economic evaluation, evaluation methodology, epidemiology, biostatistics, systematic reviews, clinical trials and health technology assessment. Economic evaluation explicitly includes cost-effectiveness, cost-utility and cost-benefit analysis, while HTA instruction addresses the methods and tools used to support reimbursement and policy decisions.

Against the single scientific criterion applied in this review, however, the curriculum fails. No evidence was identified in the publicly available curriculum that representational measurement is taught as the scientific foundation for quantitative analysis. Students are introduced to economic evaluation and health technology assessment without first being taught that measurement must precede arithmetic or that the admissibility of arithmetic operations depends upon the measurement properties of the quantities involved.

No evidence was identified that the curriculum introduces the axioms of representational measurement, ratio measurement, admissible transformations or dimensional homogeneity. Likewise, there is no identifiable distinction between manifest attributes requiring linear ratio measurement and latent attributes requiring Rasch logit ratio measurement. Rasch measurement, specific objectivity, invariant calibration and the measurement of individual possession of latent attributes do not appear within the publicly available educational framework.

This omission is particularly striking because the program is devoted exclusively to health technology assessment. ASA 6175 teaches cost-effectiveness, cost-utility and cost-benefit analysis, while ASA 6732 introduces the concepts and methods of HTA and their application to reimbursement and policy decisions. Yet no evidence was identified that students are first required to establish whether the quantities entering these analyses satisfy the requirements of lawful quantitative measurement.

The inclusion of epidemiology, biostatistics, systematic reviews and randomized clinical trials does not resolve this deficiency. These disciplines provide methods for generating, analyzing and synthesizing evidence, but they do not establish that the numerical quantities entering economic evaluation possess ratio-scale properties. Statistical analysis cannot create lawful measurement where lawful measurement has not first been established.

The curriculum therefore reproduces the conventional Canadian HTA framework. Students are taught how to evaluate technologies, compare alternatives, undertake economic evaluations and support reimbursement decisions without first determining whether the underlying health attributes have been measured on admissible ratio scales.

The scientific criterion is straightforward. There are only two admissible ratio measures for claims concerning therapy impact: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. No evidence was identified that either requirement forms part of the Université de Montréal curriculum or constrains the methods taught within its dedicated HTA programs.

Indeed, because the Université de Montréal has established a complete graduate curriculum devoted specifically to health technology assessment, the absence of representational measurement is particularly consequential. The program prepares graduates who will subsequently teach, conduct research and advise health systems in HTA. If the foundational requirements of quantitative measurement are absent from this educational framework, they are likely to remain absent throughout subsequent professional practice.

On the publicly available evidence, the Université de Montréal curriculum does not satisfy the accepted scientific standards required for quantitative measurement. It provides comprehensive instruction in the methods of contemporary HTA while omitting the prior conditions that determine whether quantitative claims concerning therapy impact are scientifically valid. The curriculum must therefore be regarded as scientifically invalid for the quantitative assessment of therapy impact.

CANADA: CURRICULUM INVERSION IN UNIVERSITY HTA EDUCATION

The assessments of the five Canadian university programs present a remarkably consistent picture. Despite differences in institutional structure, academic emphasis and program organization, there is no evidence that any program recognizes representational measurement as the indispensable scientific foundation for quantitative claims in health technology assessment. Across all five universities, the same conceptual pattern emerges. Ratio measurement is absent as the prerequisite for quantitative analysis, the distinction between manifest and latent attributes is not established, Rasch measurement receives no meaningful attention, and the scientific principle that measurement must precede arithmetic is replaced by immediate instruction in utilities, cost-effectiveness analysis, decision modelling and related computational techniques. The result is a national pattern of curriculum inversion.

This conclusion is important because it cannot be dismissed as the characteristic of an individual institution or a particular academic tradition. The programs examined represent Canada's principal university-based teaching capacity in health economics and health technology assessment. Together they educate the researchers, analysts and policy advisers who subsequently populate universities, consulting organizations, pharmaceutical manufacturers, provincial assessment agencies and Canada's Drug Agency (CDA). They therefore establish the intellectual framework within which quantitative claims concerning therapy impact are constructed, interpreted and defended. If representational measurement is absent from these educational programs, its absence from Canadian HTA practice is entirely predictable. Curriculum inversion provides the educational mechanism through which measurement inversion is continuously reproduced.

The consistency of these findings is particularly striking because the programs differ substantially in their institutional setting. Some are located within schools of public health, others within health policy institutes or interdisciplinary graduate programs. Some emphasize economic evaluation, while others focus more broadly on evidence synthesis, outcomes research or health services research. Yet these organizational differences do not produce meaningful differences in their treatment of measurement. None of the programs identifies ratio measurement as the prerequisite for admissible arithmetic. None distinguishes the fundamentally different measurement requirements for manifest and latent attributes. None presents Rasch logit ratio measurement as the unique scientific solution for establishing possession of latent attributes. Instead, utilities, quality-adjusted life-years (QALYs), decision analysis, simulation modelling and probabilistic sensitivity analysis are consistently presented as legitimate quantitative methods, despite their dependence upon arithmetic that cannot be justified unless lawful ratio measurement has first been established.

The implications extend far beyond curriculum design. Students who are never introduced to representational measurement have no opportunity to discover that the central constructs of contemporary HTA could never have been developed had the accepted theory of measurement been applied from the outset. Utilities, multiattribute utility instruments, QALYs, incremental cost-effectiveness ratios and preference-based simulation models do not fail because they are imperfect implementations of measurement theory. They fail because representational measurement excludes them as lawful quantitative measures. Their continued use therefore depends upon successive generations of students remaining unaware of the scientific conditions that would have prevented their adoption in the first place. Curriculum inversion is thus not simply an educational omission; it is the mechanism through which a scientifically untenable analytical framework has been preserved and transmitted across the Canadian HTA community.

The Canadian findings also have international significance. Canada has made major contributions to the development and dissemination of utility-based evaluation, most notably through the Health Utilities Index (HUI), one of the world's most influential multiattribute utility instruments. The widespread adoption of HUI has reinforced the assumption that utilities provide scientifically valid quantitative measures suitable for cost-utility analysis. Yet the present assessment demonstrates that the educational programs supporting these methods do not first establish the representational measurement requirements necessary to justify such claims. The issue is therefore not the technical sophistication of utility instruments, simulation models or economic evaluation. The issue is the prior scientific question of whether the quantities entering those methods satisfy the accepted requirements for lawful ratio measurement. If they do not, no subsequent statistical innovation, computational sophistication or methodological refinement can transform numerical constructions into quantitative measures.

Taken together, these findings explain why the contemporary Canadian HTA paradigm has proved remarkably resistant to scientific criticism. Its survival has not depended upon demonstrating that utilities, QALYs and related analytical constructs satisfy the accepted standards of quantitative science. Rather, it has depended upon the systematic omission of representational measurement from the education of successive generations of researchers and practitioners. Had the accepted principles of representational measurement formed part of HTA education when utilities and QALYs were first proposed, those constructs could never have claimed scientific legitimacy because they fail the indispensable requirement for ratio measurement. The paradigm therefore had nowhere to go from its inception. Its subsequent development has consisted not of extending quantitative science but of extending increasingly sophisticated arithmetic applied to quantities that were never established as lawful measures. Curriculum inversion explains how this position has been reproduced throughout Canadian HTA for more than four decades.

The implications are therefore uncompromising. The issue is not one of incremental curriculum improvement or the addition of another methodological topic. Representational measurement is not an optional component of HTA education but the scientific criterion that determines whether quantitative claims are possible at all. Once that criterion is accepted, only two lawful forms of ratio measurement remain available for claims of therapy impact: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. Utilities, QALYs and preference-based simulation models cannot satisfy these requirements and therefore cannot be rescued by greater computational sophistication or methodological refinement.

The transition required is therefore one of scientific reconstruction rather than educational reform. Canadian university programs preparing future HTA researchers must be rebuilt upon the accepted principles of representational measurement, with measurement preceding arithmetic and every quantitative claim resting upon one of the only two admissible ratio measures. Until that transition occurs, Canadian HTA education will continue to reproduce a framework in which numerical construction is mistaken for quantitative measurement, arithmetic substitutes for measurement, and methodological sophistication masks the absence of the scientific foundations required for lawful quantitative inquiry.

WHAT ARE CANADIAN STUDENTS NOT BEING TAUGHT?

For students entering Canadian HTA programs, the omission of representational measurement is not simply the absence of another topic within an already crowded curriculum. It removes the scientific framework that enables them to distinguish between numbers that represent measurable quantities and numbers that merely describe, rank or summarize observations. Students are taught how to construct increasingly sophisticated economic models, estimate incremental cost-effectiveness ratios, calculate QALYs, develop decision-analytic and Markov models, and undertake probabilistic sensitivity analyses, yet they are not first introduced to the principles that determine whether the quantities entering those calculations are legitimate measures. They therefore acquire computational skills without first acquiring the scientific criteria needed to judge whether those computations are scientifically admissible.

The educational consequence is profound. Without instruction in the scales of measurement and the axioms of representational measurement, students have no framework for asking the most fundamental scientific questions. What type of attribute is being measured? Is it manifest or latent? Does the attribute possess the properties required for quantitative measurement? Has a ratio measure been established? If the attribute is latent, has a Rasch logit ratio measure been constructed? Which arithmetic operations are admissible? Does multiplication require ratio measurement? Has dimensional homogeneity been preserved? If the curriculum never introduces these questions, students cannot reasonably be expected to ask them when evaluating published research, preparing reimbursement submissions for Canada's Drug Agency (CDA) or provincial HTA organizations, or undertaking their own research.

This places graduates at a significant intellectual disadvantage. They may become highly competent users of established HTA methods while lacking the scientific tools needed to determine whether those methods satisfy the requirements of quantitative inquiry. They learn how to apply accepted analytical frameworks but not how to establish whether those frameworks rest upon lawful measurement. Utilities are accepted as though they were ratio measures, QALYs are multiplied and divided as though they represented measurable quantities, and increasingly sophisticated simulation models are constructed without first demonstrating that the variables entering those models satisfy the axioms of representational measurement. The result is an educational process that emphasizes methodological proficiency while neglecting methodological validity.

The implications are particularly important in Canada because Canadian universities have played a major role in the international development of utility-based evaluation. The Health Utilities Index (HUI), developed in Canada and widely adopted throughout the world, has become one of the principal instruments supporting cost-utility analysis and QALY estimation. Yet students are rarely introduced to the prior scientific question that should precede any application of utilities: whether preference scores derived from a multidimensional ordinal instrument can legitimately be treated as ratio measures suitable for multiplication with time. By omitting this question, Canadian curricula encourage acceptance of established methods without first examining whether the quantities upon which those methods depend satisfy the scientific requirements for admissible arithmetic.

Universities have a responsibility to equip students not merely to reproduce existing analytical practice but to evaluate it critically against established scientific standards. The scales of measurement and the axioms of representational measurement provide precisely those standards. Their omission deprives students of the conceptual framework needed to distinguish between quantitative science and numerical construction. Students are taught what HTA practitioners currently do, but they are not taught how to determine whether those practices satisfy the conditions required for lawful quantitative inference. In this respect, Canadian HTA education fails to provide the scientific foundation upon which every subsequent quantitative claim should rest.

The consequence is that curriculum inversion becomes self-perpetuating. Graduates who have never been taught the central role of ratio measurement enter academic research, pharmaceutical companies, consulting organizations, provincial assessment agencies and Canada's Drug Agency carrying forward the same assumptions that characterized their education. They teach the next generation, contribute to methodological guidance, review reimbursement submissions and publish research within the same conceptual framework. Measurement inversion is therefore continually reproduced because the educational system does not expose students to the scientific principles that would enable them to recognize it. A curriculum that omits representational measurement therefore fails not only the discipline but also the students it is intended to educate, denying them the intellectual tools necessary to distinguish lawful measurement from numerical construction.

THE FUTURE OF HTA IN CANADA

The evidence presented throughout this report leads to a single conclusion. Contemporary Canadian health technology assessment cannot claim the status of a quantitative science because it was developed without recognizing the scientific requirements of representational measurement. This is not a criticism of particular methods or institutions, but of the analytical framework itself. For more than eighty years representational measurement has defined the conditions under which quantitative claims are scientifically admissible. Had these principles been recognized when modern HTA was first developed, utilities, multiattribute utility instruments, quality-adjusted life-years (QALYs) and their associated cost-effectiveness frameworks could never have been accepted as quantitative measures of therapy impact.

The reason is straightforward. There are only two lawful forms of ratio measurement available for evaluating therapy response: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. These are the only measures that support the arithmetic operations upon which quantitative science depends. Utilities and QALYs satisfy neither requirement. They are therefore not imperfect measures awaiting methodological refinement; they are numerical constructions that cannot support the multiplication, division and proportional comparisons demanded by contemporary HTA. No degree of statistical sophistication, simulation modelling or computational complexity can overcome the absence of lawful measurement.

The curriculum assessments reported here explain why this position has persisted for more than four decades. Canadian universities do not teach representational measurement as the foundation of quantitative inquiry. Instead, students are introduced directly to utilities, QALYs, cost-effectiveness analysis and simulation modelling without first being taught the scientific conditions that determine whether these methods are admissible. Curriculum inversion therefore perpetuates measurement inversion by reproducing successive generations of researchers and practitioners who have never been introduced to the principles that would have prevented these methods from being adopted in the first place.

The implications extend beyond Canada. Canadian researchers have played a leading role in the international development of utility-based health technology assessment, particularly through the Health Utilities Index. The present findings therefore question not only Canadian educational practice but also one of Canada's most influential methodological contributions to international HTA. If utilities do not satisfy the requirements of ratio measurement, then neither Canadian nor international HTA can claim to provide scientifically valid quantitative evidence of therapy impact.

The future of HTA in Canada is therefore not one of incremental reform. Adding lectures on measurement theory or refining existing analytical methods cannot resolve a framework whose central constructs fail the accepted requirements of quantitative science. The transition required is one of scientific reconstruction. Representational measurement must become the first principle of HTA, with every quantitative claim founded upon either a linear ratio measure for manifest attributes or a Rasch logit ratio measure for latent attributes. Once this standard is accepted, every subsequent methodological decision follows directly from it.

Canada therefore faces a clear choice. It can continue to defend an analytical framework that depends upon numerical constructions lacking lawful measurement, or it can rebuild HTA upon the accepted principles of representational measurement that govern quantitative science in every other discipline. There is no middle ground. The same scientific standard that has guided quantitative inquiry for more than eighty years must now become the foundation of Canadian health technology assessment.

To facilitate this transition, Maimon Research has developed a comprehensive nine-unit curriculum that reconstructs health technology assessment from the foundations of representational measurement. The program begins with measurement rather than arithmetic and proceeds systematically through the construction of lawful quantitative claims for both manifest and latent attributes before addressing health economics, therapy evaluation and formulary assessment. A complete description of the curriculum, together with supporting teaching materials and implementation guidance, is available at on the Maimon Research website [9].

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