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REPRESENTATIONAL MEASUREMENT FAILURE IN HEALTH TECHNOLGY ASSESSMENT

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

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ABSTRACT

This report examines the publicly available program content of the principal Singapore university research programs that contribute to health technology assessment (HTA), health economics and outcomes research. It is the third investigation in a series evaluating the Singapore HTA framework against the scientific requirements of representational measurement. Previous studies demonstrated measurement inversion within the national HTA knowledge base and curriculum inversion within university teaching. The present investigation asks whether the same pattern extends to the research programs that define methodological priorities, supervise postgraduate education and influence national healthcare policy.

A single scientific criterion is applied throughout: do publicly available research programs explicitly recognize representational measurement as the indispensable foundation for quantitative claims before endorsing health economics, patient-reported outcomes, cost-effectiveness analysis, decision modelling and related HTA methods? Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch logit ratio measurement. These principles constitute the accepted scientific conditions that must be satisfied before arithmetic operations can support quantitative claims concerning therapy impact.

The findings are unequivocal. Singapore universities provide sophisticated education and research in health economics, outcomes research, epidemiology, health services research, patient-reported outcomes, economic evaluation, simulation modelling and evidence-based healthcare. However, no evidence was identified that the publicly available program content explicitly recognizes representational measurement, ratio measurement or the distinction between manifest and latent attributes as the prerequisite for quantitative analysis. The result is program-content inversion: analytical methods are presented before the scientific conditions required to justify their arithmetic have been established.

Taken together, the three Singapore investigations demonstrate a coherent national pattern in which measurement inversion is reproduced through the HTA knowledge base, university curricula and institutional research programs. Singapore has faithfully adopted the contemporary international HTA paradigm, but that paradigm rests upon quantitative constructs that fail the accepted standards of representational measurement. The report concludes that further refinement of utilities, QALYs and reference-case simulation models cannot resolve this foundational problem. The required response is a transition to a new HTA paradigm founded upon lawful ratio measurement: linear ratio measures for manifest attributes and Rasch logit ratio measures for latent attributes. Only within such a framework can claims for therapy impact become scientifically evaluable, replicable and falsifiable.

INTRODUCTION

Two previous investigations have examined the Singapore health technology assessment (HTA) knowledge base against the scientific requirements of representational measurement. The first evaluated the Singapore HTA knowledge base as a whole, while the second examined the university curriculum through which that knowledge base is transmitted to future practitioners [1] [2]. Together, these investigations demonstrated a consistent pattern of measurement inversion and curriculum inversion. Contemporary HTA methods received strong endorsement, while the scientific principles required to support quantitative claims received little or no explicit recognition.

The Singapore HTA knowledge base comprises the interconnected academic, government, research and professional sources through which the accepted principles and methods of HTA are taught, transmitted and reproduced. It is not confined to a single degree program or designated HTA curriculum. Rather, it is distributed across teaching and research in health economics, public health, epidemiology, pharmacy, health services research, evidence-based medicine, outcomes research and healthcare policy. Together, these activities establish the methodological expectations that students, researchers and practitioners bring to the evaluation of therapies and the formulation of quantitative claims.

The present investigation examines a third component of this distributed knowledge base: the publicly available program content of the principal Singapore university research programs that contribute to HTA, health economics and outcomes research. The objective is not to evaluate institutional reputation, research productivity or publication volume. Rather, it is to determine whether the publicly presented activities, research priorities, methodological frameworks, educational programs and professional training explicitly recognize representational measurement as the scientific foundation for quantitative claims before endorsing or applying the methods of contemporary HTA.

This distinction is important. The previous curriculum investigation demonstrated what Singapore universities teach. The present study asks whether the research programs themselves reproduce the same conceptual framework. Research centers do more than conduct research. They establish methodological priorities, supervise postgraduate students, provide professional education, develop collaborative networks, disseminate analytical methods and influence healthcare policy. Their publicly available program content therefore provides a direct indication of the scientific framework that the institutions themselves regard as foundational.

The review applies a single criterion throughout. Does the publicly available program content explicitly recognize representational measurement, ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch logit ratio measurement before introducing health economics, patient-reported outcomes, cost-effectiveness analysis, decision modelling and related HTA methods? If these requirements are absent while the conventional analytical framework is prominently endorsed, the result is program-content inversion. This would complete a coherent pattern in which the Singapore HTA knowledge base, the university curriculum and the institutional research programs all reproduce the same departure from the accepted scientific standards of representational measurement.

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 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 [3] [4] . 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 [5]. 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 CRITICAL ROLE OF RATIO SCALES

The analysis of the Singapore program content 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 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.

THE SINGAPORE HTA PROGRAM-CONTENT KNOWLEDGE BASE

The Singapore health technology assessment (HTA) program-content knowledge base comprises the interconnected university research programs, academic centers, research institutes and associated educational activities through which the accepted principles and methods of HTA are publicly presented, promoted and reproduced. It is not confined to a single research center or designated HTA institute. Rather, it is distributed across publicly described programs in health economics, public health, epidemiology, pharmacy, health services research, evidence-based medicine, outcomes research and healthcare policy. Collectively, these research programs define the methodological framework within which quantitative claims concerning therapies, health technologies and healthcare interventions are developed, interpreted and disseminated.

At the national level, the Agency for Care Effectiveness provides the principal methodological reference point for Singapore HTA. Its methods guidance and assessment framework establish the analytical environment within which evidence is evaluated for healthcare decision making. Clinical effectiveness, safety, economic evaluation, cost-effectiveness analysis, cost-utility analysis, health-related quality of life and decision-analytic modelling occupy central positions. These methods influence not only national HTA practice but also the research priorities and analytical approaches adopted by university-affiliated research programs.

The university program-content knowledge base is concentrated principally within the National University of Singapore and Duke–NUS Medical School, together with associated research centers and health services research activities. The Saw Swee Hock School of Public Health presents substantial research and educational programs in health economics, health technology assessment, epidemiology, evidence synthesis, economic evaluation and healthcare policy. Pharmacy and pharmaceutical sciences contribute research in medication use, patient-reported outcomes, preference assessment and economic evaluation. Duke–NUS Medical School complements these activities through programs in health services and systems research, health economics, implementation science, decision analysis and evidence-informed healthcare. Together these institutions present a multidisciplinary research framework extending beyond individual projects or formal academic courses.

The wider program-content knowledge base also includes publicly available descriptions of research priorities, methodological frameworks, research themes, collaborative initiatives, graduate education, professional development, publications and policy engagement. These activities provide an institutional statement of what constitutes acceptable quantitative inquiry within Singapore HTA. Because Singapore's university and healthcare systems are closely integrated, accepted methodological conventions are reproduced through research programs, postgraduate supervision, professional training, publications, advisory activities and continuing collaboration with national healthcare institutions. Health economics, economic evaluation, utilities, QALYs, patient-reported outcomes, real-world evidence and decision-analytic modelling consequently form a mutually reinforcing program framework.

The defining characteristic of this program-content knowledge base is its emphasis on analytical application rather than measurement foundation. The publicly available programs describe methods for evidence synthesis, economic evaluation, statistical analysis, modelling, patient-reported outcomes, implementation science and healthcare decision making. What is not presented as a prior methodological requirement is a formal theory of measurement. The specification of the target attribute, representational measurement, admissible transformations, dimensional homogeneity, unidimensionality, and the distinction between manifest and latent attributes do not provide the organizing framework for the research programs themselves.

The Singapore HTA program-content knowledge base is therefore extensive in analytical capability but bounded by the accepted international HTA paradigm. Its component institutions demonstrate substantial expertise in health economics, epidemiology, statistics, pharmacy, health services research and decision science. However, these disciplines are publicly presented within a framework in which numerical representations are generally accepted before their status as measures has been established. The present investigation examines the consequences of this institutional structure by asking a single question: do Singapore's university research programs establish representational measurement as the scientific foundation for quantitative claims, or do they reproduce the same pattern of program-content inversion identified previously within the national HTA knowledge base and the university curriculum?

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

PROGRAM CONTENT REVIEW: SINGAPORE

Universities and Programs Reviewed

National University of Singapore

Saw Swee Hock School of Public Health
MSc in Health Economics and Outcomes Research
Health Services Research and related public-health programs
Department of Pharmacy and Pharmaceutical Sciences
Centre for Health Intervention and Policy Evaluation Research

Duke–NUS Medical School

Programme in Health Services Research and Population Health
Graduate Certificate Programme in Health Economic Evaluation
Health Services and Systems Research doctoral training

Nanyang Technological University

Lee Kong Chian School of Medicine
Health Services and Outcomes Research activities
Economics research in health economics and ageing
Health Outcomes, Economics and Sustainability research

Singapore Management University

School of Economics
Health Economics and Management teaching
SMU–SingHealth healthcare-management education

Purpose

This review evaluates the publicly available program content of Singapore universities against a single scientific criterion: whether representational measurement is explicitly recognized as the foundation for quantitative claims before the programs endorse or apply the methods of health economics, outcomes research and health technology assessment.

Particular attention is given to ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch logit ratio measurement. These constitute the scientific conditions that must be satisfied before arithmetic operations can support valid claims concerning therapy impact.

Program Content Reviewed

The review covers publicly available university research, educational and professional-training programs in Singapore that contribute directly to health economics, outcomes research, health services research, pharmacoeconomics, health technology assessment and healthcare decision-making.

The programs reviewed are concentrated principally at the National University of Singapore, Duke–NUS Medical School, Nanyang Technological University and Singapore Management University. No comparable university-level HTA or HEOR program was identified in the publicly available material reviewed for the remaining Singapore autonomous universities. Their omission from the detailed assessment does not imply institutional failure; it reflects the absence of a sufficiently developed and publicly identifiable HTA or HEOR program to which the review criterion could reasonably be applied.

Program content reviewed includes:

- Research program descriptions
- Degree and certificate curricula
- Course descriptions
- Methodological statements
- Research priorities
- Current research activities
- Publications and research themes
- Graduate education
- Doctoral training
- Professional development
- Health economic evaluation
- Health economics and outcomes research
- Health technology assessment
- Patient-reported outcomes
- Preference assessment
- Health services and systems research
- Real-world evidence
- Cost-effectiveness analysis
- Decision-analytic modelling
- Simulation modelling
- Value-based healthcare
- Healthcare financing and policy
- Implementation science
- Population-health research
- Publicly available website material describing analytical methods and research objectives

The National University of Singapore now offers a specialized MSc in Health Economics and Outcomes Research. Its curriculum includes evidence synthesis, quantitative methods, economic methods in HEOR, economic evaluation, cost-effectiveness and budget-impact analysis, DICE simulation, patient-reported outcomes, preference assessment, causal inference, distributional cost-effectiveness analysis and modelling for HTA. The program is explicitly designed to prepare graduates to contribute to pricing, reimbursement, market access, policy evaluation and healthcare decision-making.

NUS also offers health-services-research teaching that integrates psychometrics, health economics and outcomes research, patient-reported outcomes, decision-analytic modelling, real-world data analysis and cost-effectiveness analysis.

Duke–NUS Medical School presents a substantial program in health services and population health research. Its stated methods include health economics, decision science, implementation science, survey research, epidemiology, quantitative medicine and data science. Its educational activities include a Graduate Certificate in Health Economic Evaluation and doctoral training incorporating decision science, simulation modelling and health economics.

Nanyang Technological University identifies research in health economics, ageing, health services, health outcomes and the economic evaluation of health and environmental interventions. Its publicly described work includes the assessment of health impacts, healthcare utilization, financial costs and the value of interventions.

Singapore Management University offers teaching in health economics and health economics and management. Publicly available course material includes healthcare-market analysis, healthcare financing, economic analysis of healthcare systems, financial modelling and evidence-based policy recommendations.

A. REPRESENTATIONAL MEASUREMENT

Topic	Explicitly recognized	Program evidence
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	—
Unidimensionality as a measurement requirement	No evidence identified	—
Manifest and latent attributes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Rasch measurement as a requirement for latent attributes	No evidence identified	—
Person-item conjoint measurement	No evidence identified	—
Specific objectivity and invariance	No evidence identified	—
Rasch logit ratio measurement	No evidence identified	—
Attribute possession	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

B. CONTEMPORARY HTA FRAMEWORK

Topic	Explicitly recognized	Program evidence
Health economics and outcomes research	Yes	NUS specialized MSc and related research
Health economics	Yes	NUS, Duke–NUS, NTU and SMU teaching and research
Health technology assessment	Yes	NUS MSc and modelling courses
Economic evaluation	Yes	NUS and Duke–NUS education
Cost-effectiveness analysis	Yes	NUS curriculum and health-services-research teaching
Budget-impact analysis	Yes	NUS economic methods curriculum
Distributional cost-effectiveness analysis	Yes	NUS elective curriculum
Pharmacoeconomics	Yes	Pharmacy and HEOR-related research and teaching

Patient-centered outcomes research	Yes	NUS HEOR program
Patient-reported outcomes	Yes	NUS curriculum and health-services-research teaching
Preference assessment	Yes	NUS HEOR curriculum
Psychometrics	Yes	NUS health-services-research teaching
Health services research	Yes	NUS and Duke–NUS programs
Health systems research	Yes	Duke–NUS core program
Population-health research	Yes	Duke–NUS and NUS research
Real-world evidence and data	Yes	NUS research and teaching
Decision-analytic modelling	Yes	NUS and Duke–NUS teaching
Simulation modelling	Yes	NUS DICE course and Duke–NUS doctoral training
Mathematical modelling for HTA	Yes	NUS elective curriculum
Evidence synthesis and meta-analysis	Yes	NUS MSc curriculum
Causal inference	Yes	NUS elective curriculum
Implementation science	Yes	Duke–NUS research program
Value-based healthcare	Yes	NUS and Duke–NUS program objectives
Healthcare financing	Yes	NUS and SMU teaching
Pricing, reimbursement and market access	Yes	NUS MSc program
Healthcare policy	Yes	NUS, Duke–NUS and SMU
Graduate HEOR education	Yes	NUS MSc
Doctoral health-services-research training	Yes	Duke–NUS PhD track
Professional health-economic training	Yes	Duke–NUS certificate and SMU–Sing Health education
Advanced quantitative analysis	Yes	NUS and Duke–NUS curricula

Assessment

Singapore universities present a substantial and increasingly explicit educational and research framework in health economics, outcomes research, health services research and health technology assessment. This framework is concentrated principally at the National University of Singapore and Duke–NUS Medical School, with additional contributions from Nanyang Technological University and Singapore Management University.

The National University of Singapore occupies the leading position. Its MSc in Health Economics and Outcomes Research represents a comprehensive professional curriculum expressly directed toward HTA, economic evaluation, pricing, reimbursement, market access and healthcare decision-making. The curriculum includes evidence synthesis, epidemiology, regression and survival analysis, economic evaluation, cost-effectiveness analysis, budget-impact analysis, patient-reported outcomes, preference assessment, causal inference, simulation modelling and distributional cost-effectiveness analysis.

Duke–NUS complements this program through research and training in health economics, health services research, implementation science, decision science, simulation modelling, population health and value-based healthcare. Its Graduate Certificate in Health Economic Evaluation is designed to enable participants to conduct and critically assess economic evaluations, while its doctoral program includes health economics, decision science and simulation modelling as principal methodological disciplines.

NTU and SMU extend the national framework through health-economics research, healthcare-policy analysis, health-outcomes research, economic evaluation, healthcare financing and management education. Although their involvement is less specialized than the NUS and Duke–NUS programs, they reinforce the broad institutional acceptance of economic and quantitative methods for healthcare evaluation.

Against the scientific criterion applied in this review, however, the Singapore HTA knowledge framework fails at the foundational level. No evidence was identified in the publicly available program descriptions and curricula reviewed that representational measurement is recognized as the prerequisite for quantitative claims.

The public material does not establish that measurement must precede arithmetic. It does not explain that the legitimacy of addition, subtraction, multiplication and division depends upon the measurement scale on which an attribute is represented. It does not identify ratio measurement, equal units and a non-arbitrary zero as prerequisites for multiplication and division. Nor does it address admissible transformations or dimensional homogeneity.

This absence is particularly significant because the programs describe their quantitative and economic methods as foundational, rigorous or advanced. At NUS, for example, the course titled Quantitative Foundation for HEOR concentrates on epidemiological design, bias, confounding, regression analysis and survival analysis. These are important statistical subjects, but they do not establish a measurement foundation. Statistical techniques operate on numerical observations after the relevant attribute has been measured; they do not determine whether the numbers entering the analysis constitute a measure.

Similarly, the NUS course Economic Methods in HEOR describes the principles of HTA and modelling, cost-effectiveness analysis, budget-impact assessment and economic evaluation as foundational methods. The curriculum therefore defines the foundation of HEOR in terms of accepted analytical procedures rather than the prior scientific requirements of measurement.

The distinction is decisive. A research design may be internally valid, a regression model may be correctly specified and a simulation may be technically sophisticated, yet none of these achievements establishes that the variables subjected to arithmetic possess the required measurement properties. Analysis cannot create measurement retrospectively.

The treatment of patient-reported outcomes illustrates the problem directly. The NUS curriculum describes patient-reported outcomes as assessments of quality of life, functional status and symptom burden and presents them as fundamental inputs to health-economic research, economic evaluation and modelling. It also introduces preference assessment as a means of quantifying the relative importance of treatment and service attributes.

No evidence was identified, however, that the program first distinguishes observations, scores and preferences from measures. No explicit requirement was identified that a patient-reported instrument must define a single latent attribute, establish unidimensionality, construct invariant equal units, demonstrate specific objectivity or support a Rasch logit continuum before change scores or therapy impacts are calculated.

The public reference to psychometrics does not resolve this problem. NUS health-services-research teaching combines psychometrics with patient-reported outcomes, health economics, decision modelling and cost-effectiveness analysis, but the publicly available description does not indicate that Rasch measurement is recognized as the necessary basis for constructing a latent-attribute measure.

No evidence was identified that the Singapore programs distinguish manifest from latent attributes. This is a foundational omission because the two attribute classes require different forms of measurement.

Manifest attributes are directly observable and may support linear ratio measurement when the unit, counting rule and non-arbitrary zero are clearly defined. Examples include hospital days, emergency visits, treatment administrations, readmissions, hours of care and medication units.

Latent attributes such as pain, fatigue, physical function, treatment satisfaction, quality of life or need fulfilment cannot be observed directly. They require construction of a unidimensional invariant continuum through conjoint measurement of persons and items. Within the criterion applied here, that requires Rasch measurement and expression on a Rasch logit ratio scale.

The reviewed programs do not publicly identify these as the two admissible measurement pathways for claims concerning therapy impact. Patient-reported scores, preferences, health outcomes, costs and model outputs are instead incorporated into analysis without a prior, explicit demonstration that the attributes have been measured on scales permitting the proposed arithmetic.

The result is program inversion.

The inversion is especially clear in the NUS MSc HEOR curriculum. The program proceeds from evidence synthesis and quantitative analysis to economic evaluation, simulation, patient-reported outcomes, preference assessment and distributional cost-effectiveness analysis. Yet the prior questions are not publicly addressed:

What is the attribute?

Is it manifest or latent?

What empirical relational structure is being represented?

What scale type has been constructed?

What transformations are admissible?

Which arithmetic operations are permitted?

Are the units equal?

Is the zero non-arbitrary?

Is dimensional homogeneity preserved?

If the attribute is latent, has an invariant unidimensional Rasch continuum been constructed?

Without answers to these questions, the curriculum teaches students how to manipulate numerical representations before establishing whether those representations constitute measures.

The Singapore framework therefore does not merely omit one specialized methodological topic. It omits the criterion that determines whether the subsequent quantitative methods are scientifically permissible. Cost-effectiveness analysis, budget-impact modelling, preference assessment, distributional analysis and simulation do not remedy that omission. They amplify it by combining and transforming numbers whose measurement status has not first been established.

The educational consequences are substantial. Singapore is developing a specialized body of HEOR practitioners trained to support government, healthcare systems, HTA agencies, pharmaceutical companies, medtech firms and market-access decisions. The NUS MSc is explicitly positioned to prepare graduates for pricing, reimbursement, patient access and policy evaluation across Singapore and Asia.

If the curriculum does not recognize representational measurement, each graduating cohort may reproduce the same inversion: arithmetic before measurement, modelling before scale justification and decision claims before the relevant attributes have been validly quantified.

The national character of the failure makes the result more consequential than the failure of a single department. NUS, Duke–NUS, NTU and SMU contribute different elements, but their public programs collectively endorse a common contemporary framework. Health economics, health-services research, patient-reported outcomes, preference assessment, cost-effectiveness analysis, simulation, implementation science and value-based healthcare are all recognized. The prior requirements of representational measurement are not.

There is therefore no evidence in the reviewed public material of a competing Singapore university program that corrects the omission. No institution was identified as requiring ratio measurement before multiplication, dimensional homogeneity before combining attributes, or Rasch logit measurement before making quantitative claims for latent therapy impact.

Once ratio measurement is accepted as the non-negotiable standard, the present university framework cannot stand unchanged. Reconstruction must begin with the definition of the target attribute and proceed through the requirements of representational measurement before statistical analysis, economic evaluation or modelling is introduced.

All claims for manifest therapy impacts should be expressed through properly defined linear ratio measures. All claims for latent therapy impacts should be expressed through Rasch logit ratio measures that satisfy the requirements for unidimensionality, invariance, conjoint measurement and specific objectivity.

This reconstruction would not require abandoning empirical research, evidence synthesis, causal inference, statistics or modelling. It would require placing them in their proper scientific order. Measurement must be established first. Arithmetic, statistical analysis and modelling may follow only where the scale properties of the variables permit them.

The publicly available educational and research programs of Singapore universities demonstrate extensive endorsement of the contemporary health economics, outcomes research and HTA framework. Singapore offers specialized graduate education in HEOR, professional training in economic evaluation, doctoral study in health-services research and university programs in health economics, health policy, patient-reported outcomes, real-world evidence, simulation and value-based healthcare.

Against the single criterion applied in this review, however, the result is unequivocal. No evidence was identified that representational measurement is explicitly recognized as the foundation for quantitative claims. Ratio measurement, admissible transformations, dimensional homogeneity, the distinction between manifest and latent attributes, and Rasch logit ratio measurement are absent from the publicly described framework.

Singapore's universities therefore exhibit a common pattern of program inversion. They begin with economic evaluation, statistics, patient-reported outcomes, preferences, cost-effectiveness analysis and modelling without first establishing whether the attributes entering those procedures have been measured.

The failure is not confined to one university. It characterizes the publicly presented national university framework. Its significance is magnified by the creation of a specialized MSc in HEOR intended to prepare practitioners for influential roles in HTA, pricing, reimbursement, market access and healthcare policy throughout Asia.

Once the requirement for ratio measurement is applied, the conclusion follows directly. The existing framework cannot continue unchanged. It must be reconstructed around linear ratio measurement for manifest attributes and Rasch logit ratio measurement for latent attributes.

Until that reconstruction occurs, Singapore's university programs remain highly developed in economic and analytical technique but silent on the prior scientific question that determines the legitimacy of every quantitative claim: whether the relevant attribute has actually been measured.

HOW DID SINGAPORE GET HERE?

The findings presented in this review raise an obvious question. How did Singapore, with internationally respected universities, a sophisticated healthcare system and a strong commitment to evidence-based policy, arrive at a position where representational measurement is absent from the intellectual foundations of health technology assessment? The explanation does not lie in a failure of individual institutions or investigators. Rather, it reflects the way contemporary HTA has evolved internationally over the past four decades.

Singapore did not develop its HTA framework in isolation. Like many countries, it adopted the methodological conventions established elsewhere. Health economics, cost-effectiveness analysis, quality-adjusted life years (QALYs), decision-analytic modelling, patient-reported outcomes and evidence synthesis had already become accepted components of the international HTA paradigm before Singapore established its own national assessment framework. These methods were introduced as established analytical practice rather than as propositions requiring examination against the scientific principles of measurement. Consequently, the underlying assumptions of the discipline were inherited rather than critically evaluated.

Once these conventions became established, they were progressively embedded within the institutions responsible for producing and transmitting HTA knowledge. National methodological guidance endorsed the accepted analytical framework. Universities developed teaching programs based upon those methods. Research centers organized their activities around economic evaluation, modelling, outcomes research and implementation science. Academic journals published research employing the same analytical conventions, while professional societies reinforced them through conferences, methodological guidance and continuing education. Each institution drew legitimacy from the others, creating a mutually reinforcing intellectual framework.

This process explains why the present investigation, together with the earlier assessments of the Singapore HTA knowledge base and university curriculum, identifies remarkably consistent patterns. The same methodological assumptions appear in national guidance, university teaching, publicly described research programs and professional practice. What is transmitted from one generation of students to the next is not merely a collection of analytical techniques but an entire conceptual framework defining what counts as acceptable quantitative evidence.

The critical omission is that this framework does not begin with measurement. Students and researchers learn how to construct models, estimate costs and outcomes, analyze uncertainty and interpret cost-effectiveness ratios. They are not first required to establish whether the quantities entering those analyses satisfy the conditions necessary for arithmetic. The accepted principles of representational measurement of ratio measurement, admissible transformations, dimensional homogeneity, unidimensionality and the distinction between manifest and latent attributes remain largely absent from the publicly presented methodological foundation of the discipline.

This omission has profound consequences. The central quantitative constructs of contemporary HTA depend upon arithmetic performed on quantities whose measurement status has not been established. Utilities, QALYs and simulated cost-effectiveness ratios are therefore accepted because they have become institutional convention rather than because they satisfy the accepted requirements of quantitative science. The resulting framework is internally coherent only while its measurement assumptions remain unexamined. Once representational measurement is introduced as the governing scientific criterion, the' they it. Graduates trained within the same framework become the next generation of researchers, reviewers and teachers. Scientific legitimacy is inferred from institutional acceptance rather than from compliance with the axioms of representational measurement.

The question, therefore, is not why Singapore failed to recognize representational measurement. The more important question is why contemporary HTA, internationally, evolved along a path in which arithmetic came to precede measurement. Singapore has faithfully reproduced that international paradigm. The evidence presented in this and the preceding investigations suggests that the result is not simply methodological conservatism but the institutional reproduction of a framework whose central quantitative claims cannot be sustained once the accepted principles of representational measurement are applied.

CONCLUSION

Representational measurement provides the indispensable foundation for quantitative science. Without lawful measurement there can be no lawful arithmetic, and without lawful arithmetic there can be no scientifically defensible quantitative claims. The investigations presented in this series demonstrate that this foundation is absent from the contemporary Singapore HTA framework. Examination of the national HTA knowledge base, the university curriculum knowledge base and the publicly available program content of Singapore's leading university research programs reveals the same consistent pattern. Contemporary HTA methods are strongly endorsed while the scientific principles required to support quantitative claims receive little or no explicit recognition. Together, these investigations demonstrate that measurement inversion, curriculum inversion and program-content inversion characterize the Singapore HTA framework as a whole.

The governing scientific standard is neither controversial nor new. For more than eighty years representational measurement has required that arithmetic operations be determined by the properties of the measurement scale. Multiplication and division require ratio measurement. Claims concerning manifest attributes require linear ratio measures, while claims concerning latent attributes require Rasch logit ratio measures. These are the only scientifically admissible foundations for quantitative claims of therapy impact. They are not methodological preferences but the conditions that distinguish quantitative science from the manipulation of numerical representations.

When these standards are applied, the implications for contemporary HTA are unavoidable. Utilities, multiattribute preference instruments, QALYs, incremental cost-effectiveness ratios and reference-case simulation models cannot satisfy the requirements for lawful quantitative measurement. Their continuing refinement through increasingly sophisticated statistical techniques, computational methods, artificial intelligence or real-world evidence cannot resolve this deficiency because modelling cannot create measurement retrospectively. The difficulty lies not in implementation but in the absence of lawful measures entering the analysis. The present HTA paradigm therefore represents an intellectual cul-de-sac. Once its foundational assumptions concerning measurement are recognized as invalid, there are no scientifically defensible next steps within the existing framework.

The challenge now facing Singapore's universities, researchers and students is not to defend the existing paradigm but to recognize the necessity of building its successor. Contemporary HTA has followed a false scientific pathway. Beginning with the decision to value health states through multiattribute preference scores, every subsequent stage of the reference-case framework has proceeded in defiance of the axioms and scale requirements of representational measurement. The solution, however, is remarkably straightforward. The new paradigm begins where every quantitative science begins: with lawful measurement. Claims for manifest attributes must be supported by linear ratio measures. Claims for latent attributes must be supported by Rasch logit ratio measures. Once these foundations are established, the remaining components of HTA follow naturally. Study design, evidence generation, formulary assessment and therapy evaluation can all be reconstructed around claims that are evaluable, replicable and falsifiable.

To support this transition, Maimon Research has developed a comprehensive curriculum that reconstructs health technology assessment from the first principles of representational measurement. The program provides a practical pathway for universities, researchers, students and HTA practitioners wishing to move from the limitations of the existing framework to a scientifically coherent alternative. Readers are encouraged to explore this new paradigm. The future of HTA lies not in refining measurement inversion, but in embracing the scientific discipline that follows once lawful measurement becomes the foundation of every quantitative claim. A complete description of the curriculum, together with supporting teaching materials and implementation guidance, is available at on the Maimon Research website [6].

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