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ARTIFICIAL INTELLIGENCE LARGE LANGUAGE MODEL INTERROGATION

REPRESENTATIONAL MEASUREMENT FAILURE IN HEALTH TECHNOLGY ASSESSMENT

SINGAPORE: NORMAL SCIENCE AND THE ABSENCE OF REPRESENTATIONAL MEASUREMENT IN HTA EDUCATION

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ABSTRACT

Health technology assessment (HTA) depends upon quantitative claims whose scientific legitimacy requires measurement to precede arithmetic. Scale properties determine admissible mathematical operations; multiplication and division require ratio measurement; dimensional homogeneity must be maintained; and manifest and latent attributes require distinct measurement pathways. This study examines whether these requirements provide the scientific foundation for the publicly available Singapore HTA, health-economics and outcomes-research program-content knowledge base. Singapore provides a particularly important test because graduate education, academic research, health-services evaluation and national healthcare decision-making operate within a sophisticated and closely connected environment encompassing the National University of Singapore, Duke-NUS Medical School and the Agency for Care Effectiveness.

*A fixed 37-topic framework was applied, comprising 17 topics defining representational measurement and 20 defining contemporary HTA and health economics. The interrogation produced a categorical result**:** 0/17 representational-measurement topics were explicitly recognized as foundations of the program-content knowledge base, while 20/20 contemporary HTA topics were represented**.** The latter include economic evaluation, utilities, QALYs, ICERs, decision analysis, Markov modelling, simulation, probabilistic sensitivity analysis, value-of-information analysis and budget impact. The finding therefore represents program-content inversion rather than a simple curricular imbalance: the analytical apparatus for manipulating and modelling numerical values is extensively developed while the prior measurement framework required to establish the admissibility of those operations is not explicitly represented.*

The result is particularly consequential because Singapore's quantitative HTA environment is institutionally mature and extends from graduate education through academic research to national technology assessment and healthcare decision-making. Analytical sophistication cannot compensate for measurement failure: modelling, simulation and sensitivity analysis cannot confer ratio properties, establish dimensional homogeneity or transform numerical assignments into measures.

The required response is therefore transformation rather than curriculum expansion. Representational measurement must become the organizing scientific foundation of quantitative therapy evaluation. Students should progress from attributes and scale properties through admissible arithmetic and ratio measurement to linear ratio measurement for manifest attributes and Rasch measurement for latent attributes, culminating in empirically evaluable, replicable and falsifiable therapy-impact claims. The Maimon Research nine-unit transformation program provides a structured framework for faculty preparation, curriculum development and institutional transition toward this post-legacy model of HTA.

INTRODUCTION

Health technology assessment (HTA) depends upon quantitative claims. These claims are scientifically defensible only when measurement precedes arithmetic and the properties of the measurement scale permit the mathematical operations performed. Multiplication and division require ratio measurement; arithmetic must respect admissible transformations and dimensional homogeneity; and manifest and latent attributes require different approaches to measurement. The question is the extent to which the constraints of scales of measurement and the axioms of representational measurement are recognized as an essential part of any HTA curriculum [1 2] .

Previous interrogations of HTA knowledge bases in Australia, Canada, New Zealand and the United States have identified a consistent pattern of measurement inversion . The principles required for lawful measurement receive weak recognition, while utilities, QALYs, cost-effectiveness analysis and simulation modelling are strongly endorsed. Curriculum inversion reproduces the same failure educationally: students are introduced to the analytical methods of contemporary HTA without first being provided with the measurement principles required to determine whether the arithmetic underlying those methods is admissible .

The present investigation extends earlier research-center program-content assessments by examining the Singapore HTA, health-economics and related quantitative health-research program-content knowledge base as a whole. Singapore provides an especially important setting because of the concentration, sophistication and international standing of its academic and healthcare environment. Major programs and research activities associated with the National University of Singapore (NUS), Duke-NUS Medical School, Nanyang Technological University (NTU) and associated academic health systems encompass health economics, economic evaluation, outcomes research, health-services research, population health, patient-reported outcomes, health policy and quantitative decision making. These activities operate within a wider national healthcare-evaluation environment that includes the Ministry of Health and Agency for Care Effectiveness (ACE). Singapore therefore provides a distinctive environment in which to examine the scientific foundations underlying contemporary quantitative health research and its relationship to healthcare decision making.

The unit of analysis is not an individual university, research center, agency or investigator. It is the publicly available program content through which the Singapore HTA and health-economics knowledge base is expressed and reproduced. This includes teaching and training, program and course descriptions, research priorities, methodological statements, projects, publications, seminars and other publicly available descriptions of what relevant Singapore programs research, apply and teach. Where relevant, publicly available materials associated with the wider national HTA and healthcare-evaluation environment provide additional context. The purpose is therefore to characterize the Singapore program-content knowledge **base** rather than to infer what individual faculty members, researchers or decision makers may know or address outside that publicly presented framework.

Two contrasting bodies of content are assessed using the fixed 37-topic framework. The first comprises 17 topics representing the requirements of representational measurement, including measurement preceding arithmetic, scales of measurement, admissible transformations, ratio measurement, dimensional homogeneity, the distinction between manifest and latent attributes, linear ratio measurement and Rasch measurement. The second comprises 20 topics representing contemporary health economics and HTA, including health economics, economic evaluation, utilities, QALYs, cost-effectiveness and cost-utility analysis, patient-reported outcomes, decision analysis, simulation and microsimulation, uncertainty analysis, value-of-information analysis, budget impact and related methods.

The question is deliberately narrow: does the Singapore HTA and health-economics program-content knowledge base establish representational measurement as the foundation for quantitative claims before introducing or applying the arithmetic of contemporary HTA? If the requirements of representational measurement are absent while conventional HTA methods are extensively represented, the result is program-content inversion: an educational and research environment in which arithmetic and modelling proceed without first establishing that the quantities involved possess the measurement properties required to support the operations performed.

Singapore adds an important dimension to this question because of the close relationship between academic health research, professional education and national healthcare decision making. Unlike a setting in which university teaching and applied HTA can be considered largely separate environments, Singapore's relatively concentrated healthcare and academic infrastructure creates the potential for methodological assumptions to move readily between universities, academic health systems, healthcare institutions and national evaluation. Methods transmitted through graduate education can therefore become methods subsequently employed in research, technology assessment, pharmaceutical evaluation, healthcare policy and resource-allocation decisions.

This makes the measurement question particularly consequential. The issue is not whether Singapore possesses quantitative expertise. It clearly does**.** Nor is it whether its universities, researchers and healthcare institutions successfully employ the internationally established methods of contemporary health economics and HTA. The question is whether the numerical quantities entering those methods have first been required to satisfy the measurement conditions governing the arithmetic subsequently performed upon them. International acceptance, methodological sophistication and incorporation into national decision processes cannot themselves establish measurement status.

This distinction is fundamental. Representational measurement is not another methodology that can simply be added to contemporary HTA. It establishes the scientific rules governing the admissibility of arithmetic itself. Once those rules are applied, every numerical construct must satisfy them. The Singapore review therefore assesses whether lawful measurement provides the scientific foundation for its HTA and health-economics program content or whether the legacy framework of contemporary HTA occupies that position without it. Given the sophistication of Singapore's academic health-sciences environment and its close connection with national healthcare evaluation, the assessment provides a particularly demanding test of whether contemporary HTA program content is grounded in the measurement requirements of normal quantitative science.

FOUNDATIONS OF QUANTITATIVE ANALYSIS

Before examining Singapore program content, it is important to identify the scientific principles against which that content is assessed. These are not matters of methodological preference. They are the requirements of representational measurement that determine whether quantitative claims and the arithmetic operations supporting them are admissible .

Two principles are fundamental. First, measurement must precede arithmetic. Numerical operations cannot create measurement where measurement does not exist. Second, the arithmetic performed must be admissible for the measurement scale concerned. Operations involving multiplication, division and ratios require ratio measurement. For claims of therapy impact in HTA, this requires linear ratio measurement for manifest attributes or Rasch measurement for latent attributes.

These requirements establish the boundary between the manipulation of numbers and lawful quantitative measurement. Contemporary Singapore HTA and health economics, by contrast, are organized around economic evaluation, utilities, QALYs, cost-effectiveness and cost-utility analysis, decision analysis and modelling. These methods are deeply embedded within Singapore's academic, research and national healthcare-evaluation environment, including major activities associated with the National University of Singapore, Duke-NUS Medical School and the Agency for Care Effectiveness, together with the wider Ministry of Health environment. Singapore is therefore distinctive in having a relatively concentrated relationship between graduate education, health-economic research and the application of HTA methods to national healthcare decision making.

Institutional acceptance, methodological sophistication and incorporation into national decision processes, however, do not determine measurement status. Nor does conformity with internationally accepted HTA practice establish that the numerical quantities employed possess the properties required for the operations performed upon them. The prior scientific question remains whether the quantities entering economic evaluations, QALYs, ICERs and decision models have first been established as measures possessing the properties required for their arithmetic. Increasingly sophisticated modelling cannot retrospectively provide measurement properties that were absent from the quantities entering the analysis.

The Singapore program-content review therefore asks a straightforward question: does the publicly available Singapore HTA and health-economics knowledge base recognize representational measurement as the foundation for quantitative claims, or does it proceed directly to the methods and arithmetic of contemporary HTA without first establishing their measurement admissibility**?** Because the Singapore knowledge base extends from university education and research into national technology assessment and healthcare decision making, the question has implications beyond curriculum content. It concerns the scientific foundation of the quantitative framework through which evidence is taught, generated, evaluated and ultimately used to inform healthcare decisions. This is the criterion governing the analysis that follows.

MEASUREMENT BEFORE ARITHMETIC

Before students are introduced to health technology assessment, health economics, cost-effectiveness analysis or decision modelling, they should understand the scientific conditions that determine whether quantitative claims are possible. The governing principle is straightforward: measurement must precede arithmetic. Numbers cannot be manipulated legitimately merely because they have been assigned to observations. The properties of the measurement scale determine which arithmetic operations are admissible.

Representational measurement provides this foundation. The target attribute must first be identified and defined, its measurement properties established, and the appropriate scale constructed. Only then can arithmetic proceed. Multiplication and division require ratio measurement, admissible transformations must be respected, and dimensional homogeneity must be maintained. Reversing this sequence allows arithmetic to precede measurement and produces numerical constructions that cannot be interpreted as lawful quantitative measures.

For HTA claims of therapy impact, the distinction between manifest and latent attributes is fundamental. Manifest attributes are directly observable. Examples include survival time, hospital days, emergency department visits, treatment administrations and walking distance. Where a defined unit and non-arbitrary zero are established, these attributes support linear ratio measurement and the arithmetic permitted by a ratio scale.

Latent attributes, such as pain, fatigue, physical function or need fulfilment, cannot be observed directly. Assigning numbers to questionnaire responses or adding item scores does not establish measurement. A measurement model is required to construct a unidimensional continuum and demonstrate invariant measurement. For this purpose, Rasch measurement provides person-item conjoint measurement, specific objectivity and a logit continuum upon which possession of the latent attribute can be assessed [3].

The educational requirement can therefore be stated simply. Claims concerning manifest attributes require linear ratio measurement; claims concerning latent attributes require Rasch measurement. Students should understand these requirements before being introduced to utilities, QALYs, cost-effectiveness ratios or simulation models. Numerical constructions do not acquire measurement properties merely through arithmetic, statistical analysis or incorporation into increasingly sophisticated models.

This sequence provides the criterion for assessing Singapore's HTA and health-economics program-content knowledge base. The question is not how sophisticated its teaching, research, economic evaluation or modelling may be, nor how firmly established these methods have become across institutions such as the National University of Singapore, Duke-NUS Medical School and associated academic and health-services research environments. Nor is the question altered because these methods extend beyond universities into Singapore's national HTA environment through the Agency for Care Effectiveness and the Ministry of Health. It is whether students and researchers are first provided with the measurement principles required to determine whether the arithmetic they subsequently perform is admissible. If representational measurement, ratio measurement and the distinction between manifest and latent attributes are absent while economic evaluation, utilities, QALYs and modelling are extensively represented, the result is program-content inversion. In Singapore, the significance is heightened by the close relationship between academic education, health-economic research, HTA and national healthcare decision making: the issue concerns not a single course, institution or agency, but the scientific foundations of an integrated national program-content knowledge base.

THE CRITICAL ROLE OF RATIO SCALES

The Singapore program content assessment rests upon a fundamental requirement of representational measurement: arithmetic operations are determined by the properties of the measurement scale. Numerical values cannot legitimately be multiplied, divided or otherwise manipulated merely because numbers have been assigned. Measurement must first be established and the proposed arithmetic must be admissible for the scale concerned.

The distinction between nominal, ordinal, interval and ratio scales is therefore critical. Nominal scales classify; ordinal scales establish order; interval scales provide equal intervals but lack a non-arbitrary zero. Only ratio scales possess both equal units and a non-arbitrary zero and therefore support meaningful ratios and the multiplicative arithmetic required for quantitative claims.

This requirement has immediate consequences for Singapore HTA and health economics. QALYs multiply health-state values by time; incremental cost-effectiveness ratios divide differences in costs by differences in outcomes; and decision models combine probabilities, utilities, durations and other numerical inputs. These methods are extensively represented across Singapore's academic and national HTA environment. Where the quantities involved lack the measurement properties required for these operations, however, the arithmetic is inadmissible. Subsequent statistical analysis, modelling or simulation cannot correct that prior failure.

For claims of therapy impact, two forms of ratio measurement are relevant. Manifest attributes require linear ratio measurement. Latent attributes require Rasch measurement to construct an invariant quantitative continuum. This distinction provides the foundation for determining whether subsequent arithmetic is admissible.

The Singapore assessment therefore applies a straightforward criterion. Does the publicly available national HTA and health-economics program-content knowledge base recognize ratio measurement, admissible arithmetic, dimensional homogeneity and the different measurement requirements of manifest and latent attributes before introducing the quantitative methods of contemporary HTA? Or does it proceed directly to economic evaluation, utilities, QALYs, cost-effectiveness analysis and modelling without first establishing the measurement properties required for their arithmetic?

Ratio measurement is therefore not simply another topic within an HTA curriculum or research program. It establishes the boundary between admissible quantitative analysis and the manipulation of numbers without the measurement properties required to support that analysis. For Singapore, this criterion applies across a particularly concentrated and influential environment. The issue is therefore not whether Singapore possesses sophisticated quantitative expertise. It is whether that expertise is founded upon the measurement requirements necessary to support the quantitative claims being made.

THE KNOWLEDGE BASE: PROGRAM CONTENT AND COVERAGE

The assessment uses the large language model interrogation framework applied in previous studies of measurement and curriculum inversion. The present analysis differs in one important respect: rather than estimating categorical probabilities of endorsement, it examines whether specified scientific and methodological topics are explicitly represented in the publicly available program content of the Singapore HTA and health-economics knowledge base.

The Singapore knowledge base comprises the publicly accessible teaching, research, training and applied evaluation environment associated with universities, university-affiliated programs and national HTA activities in health economics, health technology assessment, outcomes research, health services research, economic evaluation, decision science and health policy. Material considered includes program descriptions, research priorities, methodological statements, projects, publications, seminars, training activities and related publicly available evidence. Relevant activities associated with the National University of Singapore, including the Saw Swee Hock School of Public Health and HIPER; Duke-NUS Medical School and its health-services and systems research activities; and the Agency for Care Effectiveness and associated Ministry of Health environment contribute to this national knowledge base. The objective is not to evaluate individual investigators, courses, universities or agencies, but to characterize the methodological framework represented across Singapore as a whole.

As noted above, two contrasting groups of content topic are examined. The first represents representational measurement. It includes measurement preceding arithmetic, scales of measurement, the axioms of representational measurement, ratio measurement, admissible transformations and arithmetic, dimensional homogeneity, the distinction between manifest and latent attributes, linear ratio measurement for manifest attributes, and Rasch measurement for latent attributes.

The second represents contemporary HTA. It includes health economics, economic evaluation, utilities and preference-based outcomes, QALYs, incremental cost-effectiveness ratios, decision analysis, decision trees, Markov models, simulation and microsimulation, probabilistic sensitivity analysis, value-of-information analysis and related modelling methods. Singapore provides particularly extensive representation of these methods through its university teaching and research programs, health-economics and outcomes-research activities, economic-evaluation training, health-services research and the national technology-assessment and healthcare decision-making framework associated with ACE.

The interrogation asks a single question: does the Singapore HTA and health-economics program-content knowledge base establish representational measurement as the foundation for quantitative claims before presenting the analytical methods of contemporary HTA? The criterion is the presence or absence of explicit program content rather than a probability of endorsement.

This distinction is important. Earlier interrogations demonstrated the relative strength with which knowledge bases endorsed the propositions associated with measurement inversion and curriculum inversion. Program-content interrogation provides a more direct test. If representational measurement is absent while the methods of contemporary HTA are extensively represented, the result is **program-content inversion**. Arithmetic, modelling and simulation are taught, researched and applied without representational measurement being established as the prior framework determining whether those operations are admissible.

The Singapore assessment therefore focuses on a narrow issue: whether the scientific requirements governing measurement are present in the national program-content knowledge base through which contemporary HTA and health economics are taught, researched, transmitted and applied. The purpose is to determine whether lawful measurement provides the scientific foundation for quantitative analysis in Singapore or whether the methods of the legacy HTA framework are represented without the prior measurement standards required to establish their arithmetic admissibility. Given the concentration of Singapore's academic health-economics expertise and the close relationship between university education, health-services research, national HTA and healthcare decision making, the Singapore knowledge base provides a particularly substantial test of that question.

ASSESSMENT FRAMEWORK

For this assessment, the Singapore program-content knowledge base was defined as the publicly available material describing relevant teaching and training in health economics, HTA, outcomes research, health-services research and related fields. Sources included program and curriculum descriptions, courses and modules, syllabi where available, learning objectives, seminars, workshops, teaching resources and associated educational material. Relevant national HTA materials were also considered where they contribute to the methodological environment within which quantitative healthcare evaluation is taught and applied. The purpose was to establish what students and trainees are expected to encounter across the Singapore HTA and health-economics educational environment, not what individual faculty members, researchers or agency personnel may know or address independently.

The relationship between the two components is the critical issue. Contemporary HTA methods cannot be taught independently of the measurement requirements governing their arithmetic. If students are taught that measurement precedes arithmetic, that multiplication and division require ratio measurement, and that manifest and latent attributes require different measurement strategies, they possess the scientific criteria required to judge whether subsequent HTA methods are admissible. Where these foundations are absent, utilities, QALYs, cost-effectiveness ratios and simulation models can be introduced without confronting the measurement properties required for their arithmetic.

Program-content inversion is therefore identified where contemporary HTA methods are comprehensively represented (20/20 topics) while the prior requirements of representational measurement are absent (0/17 topics). This is more than an imbalance in program content. It reverses the scientific sequence: arithmetic and modelling are introduced without first establishing the measurement conditions governing their admissibility.

Program-content inversion places contemporary Singapore HTA in direct conflict with the standards of normal quantitative science. Scientific status does not follow from generating numbers, employing sophisticated statistical methods or constructing increasingly complex models. Quantitative science requires lawful measurement, admissible arithmetic, empirical evaluation, replication and the possibility of falsification. If the foundational requirements of representational measurement are absent while utilities, QALYs, ICERs and simulation models are represented without first establishing that their arithmetic is admissible, HTA is operating outside those requirements. The 0/17 versus 20/20 result therefore identifies more than an educational deficiency. It signals separation between Singapore's HTA program-content framework and the measurement standards required by normal quantitative science.

This finding is particularly striking in Singapore because the issue cannot plausibly be attributed to a lack of quantitative expertise, academic resources or institutional commitment to HTA. Singapore has developed a sophisticated and closely connected environment. The program-content inversion identified here occurs within that highly developed academic and decision-making infrastructure. The problem is therefore not insufficient analytical sophistication, but the absence of the prior measurement framework required to determine whether that sophistication is being applied to quantities capable of supporting the arithmetic performed.

The Singapore setting makes the inversion particularly consequential because the relevant framework extends beyond university teaching. Methods introduced through graduate education and developed through academic research can subsequently contribute to technology assessment, economic evaluation, subsidy recommendations and healthcare resource-allocation decisions. The methodological pathway therefore extends from education through research to national decision making. If representational measurement is absent at the beginning of that pathway, the same absence can be reproduced throughout it. Increasing analytical sophistication downstream cannot correct a measurement failure that should have been resolved before the arithmetic began.

The two frameworks are consequently incompatible as foundations for quantitative analysis. Representational measurement requires arithmetic to be constrained by measurement. Once that principle is accepted, every subsequent quantitative method must satisfy its requirements. Numerical constructions cannot be exempted simply because they are established components of contemporary HTA, extensively taught and applied in Singapore, incorporated into national evaluation processes, or supported by decades of international methodological convention. Conversely, where representational measurement is absent from the organizing framework, there is no corresponding measurement constraint preventing such constructions from being taught, researched and applied. The Singapore 0/17 versus 20/20 result captures this incompatibility in its starkest form.

ASSESSMENT RESULTS: PROGRAM CONTENT REVIEW

Jurisdiction
Singapore

Knowledge Base
Singapore Health Technology Assessment, Health Economics and Outcomes Research Program-Content Knowledge Base

Purpose
This review evaluates publicly available program content associated with HTA, health economics, economic evaluation, outcomes research, health-services research and related quantitative health research in Singapore against the fixed 37-topic framework. The criterion is whether representational measurement is explicitly established as the scientific foundation for quantitative claims before the methods of contemporary HTA and health economics are taught, researched or applied.

The Singapore knowledge base includes major teaching, research and applied HTA activities associated with the National University of Singapore (NUS), including the Saw Swee Hock School of Public Health and its Centre for Health Intervention and Policy Evaluation Research (HIPER); Duke-NUS Medical School and its Programme in Health Services and Systems Research; and Singapore's Agency for Care Effectiveness (ACE). Relevant associated activities in health economics, outcomes research, population health, health-services research, economic evaluation and quantitative health research are also included where publicly identifiable.

The program content is unusually explicit. Duke-NUS offers graduate instruction in health technology assessment, economic evaluation and decision making and a Graduate Certificate in Health Economic Evaluation. Its published course content includes cost-effectiveness analysis, decision trees, Markov models, deterministic and probabilistic sensitivity analysis, microsimulation and discrete-event simulation. NUS HIPER identifies health economics, HTA, economic modelling, system-level HTA evaluations, costing studies, outcomes research and health-policy analysis as areas of expertise. ACE, Singapore's national HTA agency, employs clinical and economic evaluation, economic modelling, cost-effectiveness analysis, QALYs, ICERs, utilities, budget-impact assessment and value-based decision making to inform national subsidy decisions.

Topic results are presented in Table 1 for representational measurement.

TABLE 1: REPRESENTATIONAL MEASUREMENT

Topic	Explicitly recognized	Singapore program evidence
Representational measurement	No evidence identified	—

Topic	Explicitly recognized	Singapore program evidence
Scales of measurement as constraints on arithmetic	No evidence identified	—
Measurement precedes arithmetic	No evidence identified	—
Axioms of representational measurement	No evidence identified	—
Ratio measurement as prerequisite for multiplication and division	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 as distinct measurement classes	No evidence identified	—
Linear ratio measurement for manifest attributes	No evidence identified	—
Possession of latent attributes	No evidence identified	—
Rasch measurement as 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 for latent attributes	No evidence identified	—
Two admissible ratio measures for therapy impact	No evidence identified	—

Result: 0/17 representational-measurement topics explicitly recognized as foundations of the publicly available Singapore HTA/health-economics program-content knowledge base reviewed.

This result requires careful interpretation. It does not establish that no Singapore researcher knows about measurement theory or that Rasch methods have never been used in Singapore research. The criterion is considerably narrower: whether the fixed representational-measurement topics are explicitly represented as the scientific foundation governing quantitative HTA and health-economic analysis in the publicly available program-content knowledge base. In the materials reviewed, no evidence was identified that measurement preceding arithmetic, admissible transformations, ratio measurement as a prerequisite for multiplication and division, dimensional homogeneity, or the two manifest/latent measurement pathways occupy that foundational position.

The contrast with contemporary HTA is substantial.

TABLE 2: CONTEMPORARY HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly represented	Singapore program evidence
Health economics	Yes	NUS HIPER; Duke-NUS graduate teaching and research
Health technology assessment	Yes	ACE; NUS HIPER; Duke-NUS
Economic evaluation	Yes	ACE; Duke-NUS; NUS HIPER
Cost-effectiveness analysis	Yes	ACE; Duke-NUS; NUS HIPER
Cost-utility analysis	Yes	Singapore economic-evaluation research and QALY-based analyses
Pharmacoeconomics	Yes	National drug evaluation and health-economic research environment
Utilities and preference-based outcomes	Yes	ACE model inputs; Singapore health-state valuation and economic-evaluation research
Quality-adjusted life-years (QALYs)	Yes	ACE methods; Singapore cost-utility and cost-effectiveness research
Incremental cost-effectiveness ratios (ICERs)	Yes	ACE economic evaluation; Singapore cost-effectiveness studies
Measurement and valuation of health outcomes / patient-reported outcomes	Yes	Singapore HRQoL and EQ-5D valuation research
Decision analysis	Yes	Duke-NUS HTA/economic-evaluation teaching
Decision-tree modelling	Yes	Duke-NUS graduate health-economic evaluation
Markov modelling	Yes	Duke-NUS graduate and advanced HTA methods
Simulation and microsimulation modelling	Yes	Duke-NUS; NUS population-health modelling
Probabilistic sensitivity and uncertainty analysis	Yes	Duke-NUS; Singapore economic-evaluation research
Value-of-information analysis	Yes	Singapore HTA/economic-evaluation research
Budget impact analysis	Yes	ACE; NUS HIPER

Topic	Explicitly represented	Singapore program evidence
Health care priority setting and resource allocation	Yes	ACE; NUS health economics and policy activities
Value-for-money / value assessment	Yes	ACE national HTA framework
Policy, reimbursement and decision use of economic evaluation	Yes	ACE subsidy decision making; NUS/Duke-NUS policy-facing HTA

Result: 20/20 contemporary health-economics and HTA topics represented in the publicly available Singapore program-content knowledge base reviewed.

The evidence for this side of the comparison is particularly strong. ACE describes HTA as an analytical framework drawing on clinical, epidemiological and health-economic information to allocate limited healthcare resources and explicitly identifies cost-effectiveness and value for money as decision criteria. Its economic evaluation methodology uses costs, utilities, QALYs and ICERs, while budget impact contributes to the evaluation process.

The academic knowledge base reinforces rather than offsets this orientation. Duke-NUS teaches students to conduct cost-effectiveness analysis and construct decision trees and Markov models, including deterministic and probabilistic sensitivity analysis, while its advanced HTA course extends this to microsimulation and discrete-event simulation. NUS HIPER explicitly undertakes HTA involving cost-effectiveness models and budget-impact analysis and identifies economic modelling and system-level HTA evaluations among its research activities.

Value-of-information analysis is also identifiable in Singapore research. A 2026 Duke-NUS-affiliated cost-effectiveness analysis employed probabilistic sensitivity analysis, QALYs, an ICER and value-of-information analysis. Microsimulation is similarly well established: NUS researchers have developed or adapted models for diabetes, chronic disease and population-health applications, while Duke-NUS has a Singapore microsimulation project for evaluating dietary interventions.

ASSESSMENT OF INTERROGATION

The Singapore program-content interrogation produces an exceptionally stark result: 0/17 for representational measurement and 20/20 for contemporary health economics and HTA. Under the fixed 37-topic framework, no substantive evidence was identified that any of the 17 topics defining representational measurement is explicitly established as the scientific foundation governing quantitative claims. In contrast, the complete analytical apparatus of contemporary HTA is readily identifiable across university teaching, research programs and the national technology-assessment environment.

This is not a finding of limited quantitative capability. It is almost the reverse. Singapore has developed a sophisticated and closely connected HTA environment. Duke-NUS offers formal graduate education in health economic evaluation, explicitly training students in cost-effectiveness analysis, the measurement and valuation of health gains and costs, decision trees and Markov modelling. Its wider teaching also encompasses HTA and the use of economic evaluation for healthcare decision making. NUS Saw Swee Hock School of Public Health offers *Economic Methods in Health Technology Assessment*, including cost-effectiveness and budget-impact analysis, while its HIPER centre explicitly identifies cost-effectiveness, cost-utility, cost-benefit and budget-impact analyses among its core HTA capabilities.

At the national level, the Agency for Care Effectiveness is not a peripheral research group but Singapore's national HTA and clinical-guidelines agency, established by the Ministry of Health. Its purpose includes conducting technology assessments and supporting healthcare decision making. ACE's methodological environment explicitly incorporates cost-effectiveness analysis, economic evaluation and budget-impact considerations, while its published assessments report conventional QALYs and ICERs.

The 20/20 result is therefore substantive rather than nominal. Contemporary HTA is not represented merely because isolated publications happen to mention economic evaluation. It is embedded in formal graduate education, dedicated research programs and national healthcare evaluation. Singapore also hosts HTA activity covering value of information, opportunity cost, budget impact, trial-based economic evaluation and wider concepts of value. In other words, the contemporary quantitative framework is institutionally mature. That maturity makes the 0/17 result more serious rather than less.

If Singapore possessed only rudimentary HTA expertise, the absence of representational measurement might plausibly be dismissed as one component of a still-developing methodological environment. That explanation is unavailable here. Singapore has already invested extensively in the downstream analytical methods of HTA. Its students can be taught how to build cost-effectiveness models; its researchers conduct cost-utility and economic evaluations; its national agency uses economic evidence to support funding decisions. What cannot be identified in the publicly represented framework reviewed is the prior scientific architecture establishing whether the numerical quantities entering those operations possess the measurement properties required for the arithmetic performed. That is program-content inversion in its clearest form.

The distinction is not semantic. Duke-NUS describes graduate education that moves students into economic evaluation, valuation of health gains, decision-analytic modelling, decision trees and Markov models. NUS similarly describes hands-on instruction in economic evaluation, cost-effectiveness and budget impact. These are precisely the operations that should come after the measurement status of their inputs has been established. Yet within the program content examined, no equivalent foundational sequence was identified requiring students first to establish the target attribute, demonstrate the relevant measurement structure, determine scale type, identify admissible transformations, establish whether multiplication or division is legitimate, and test dimensional homogeneity.

The problem is therefore not simply that Singapore programs appear not to offer a course called *Representational Measurement*. That would be a superficial interpretation of the 0/17 result. The more consequential finding is that the scientific ordering of quantitative education appears inverted. Students are given the apparatus for operating upon numbers before the publicly represented curriculum establishes the measurement conditions that determine what those numbers can lawfully support.

The absence of ratio measurement is especially consequential. Contemporary HTA depends centrally upon multiplication and division. The QALY requires multiplication of a health-state value by time. The ICER subsequently requires division involving differences in QALYs. Budget-impact and decision models perform further combinations of numerical quantities. Yet no evidence was identified in the reviewed Singapore program content that ratio measurement is taught as the prerequisite for multiplication and division or that the ratio status of the constituent quantities must first be demonstrated.

This is not repaired by teaching the “measurement and valuation of health gains.” Duke-NUS explicitly uses such language in its health-economic evaluation curriculum. But valuation and measurement are not interchangeable scientific concepts under the framework being applied here. Assigning values to health states, eliciting preferences or generating numerical scores does not by itself establish a ratio measure or determine which transformations and arithmetic operations are admissible. The interrogation deliberately asks the more demanding question: is representational measurement explicitly governing the quantitative framework? No such evidence was identified.

The same issue applies to patient-reported and latent attributes. Singapore clearly has research involving health outcomes and valuation. NUS HIPER explicitly includes outcomes evaluation within its activities, and Singapore health-economic work operates within an established outcomes-research environment. But the existence of outcome measurement, questionnaire research or valuation work cannot be counted as recognition of the fixed representational-measurement topics unless the relevant scientific requirements are explicit. No substantive evidence was identified in the reviewed program content that latent attributes are distinguished as a separate measurement class requiring person-item conjoint measurement, specific objectivity, attribute possession and an invariant Rasch measurement structure before quantitative therapy-impact claims are made.

This qualification matters because otherwise almost any reference to “measurement” could be treated as evidence against the 0/17 finding. That would destroy the purpose of the interrogation. The criterion is not whether the word *measurement* appears. It is whether the program establishes what makes a numerical representation a measure and what arithmetic that measure permits.

The Singapore result is also unusually important because of the country's institutional concentration. ACE sits within a national healthcare system in which HTA has an explicit decision role. It assesses clinical and economic evidence for health technologies and supports funding decisions. NUS provides research and methodological expertise in HTA and economics, while Duke-NUS formally trains students in the methods used in health-economic evaluation.

The methodological implications are substantial. If the measurement foundation is absent from the beginning of that pathway, the omission need not remain confined to graduate education. It can be reproduced through research and become embedded in the numerical evidence used to support national healthcare decisions.

The ACE environment makes this especially visible. ACE was established specifically to evaluate the clinical and cost-effectiveness of health technologies and has made value and cost-effectiveness central to its institutional purpose. A published ACE analysis, for example, reports an ICER in Singapore dollars per QALY gained. Under contemporary HTA convention this is entirely routine. Under the representational-measurement framework, however, the scientifically prior questions are unavoidable: what attribute does the QALY measure, what scale has been established, what justifies multiplication of utility by time, and what permits the resulting difference in QALYs to serve as the denominator of a ratio?

The Singapore program-content knowledge base provides extensive evidence concerning how the calculation is undertaken and used. The interrogation finds no comparable explicit foundation explaining why the constituent measurements permit the calculation in the first place. This is the central meaning of the versus 20/20 result.

It would be misleading to describe it merely as a curricular "gap." A gap suggests that representational measurement could be added alongside economic evaluation as another useful subject. The finding is more fundamental. The 17 measurement topics are logically prior to the 20 contemporary-HTA topics. They establish the scientific conditions under which the latter can operate. Their absence therefore represents an inversion of scientific priorities rather than an omitted specialty.

Nor does the sophistication of the Singapore framework provide a defense. Duke-NUS offers advanced modelling methods; NUS describes sophisticated HTA and economic-evaluation capabilities; Singapore research uses simulation and other quantitative methods; and ACE operates a developed national HTA process. None of that demonstrates measurement legitimacy. Computational sophistication is downstream of measurement**.** A decision tree cannot confer ratio properties upon its inputs. A Markov model cannot supply an absolute zero to a scale that lacks one. Probabilistic sensitivity analysis cannot establish dimensional homogeneity. Microsimulation cannot transform a numerical score into a measure. Indeed, the greater the sophistication downstream, the more important it becomes to demonstrate the foundation upstream.

The result also raises an educational question that should be uncomfortable for Singapore universities. A student entering a graduate program can be taught to construct a Markov model, conduct cost-effectiveness analysis and interpret economic evidence. But if the same student is not first taught why multiplication and division require particular measurement properties, how admissible transformations constrain arithmetic, why dimensional homogeneity matters, and why manifest and latent attributes demand different measurement pathways, then the student has been given technical capability without the scientific criteria required to determine whether that capability is being lawfully applied. That is not a minor educational omission. It is entirely possible for a graduate to become highly proficient in contemporary HTA while remaining unable to answer the most elementary measurement questions: (e.g., What is an attribute?)

The responsibility cannot simply be shifted to international convention. Singapore did not invent the QALY/reference-case paradigm, and its universities and national institutions have adopted methodologies widely accepted internationally. This explains how the framework was inherited. It does not establish its scientific legitimacy. International consensus, professional convention and regulatory acceptance are sociological facts about the adoption of a methodology; they are not demonstrations that the methodology satisfies the axioms of measurement.

Nor should the 0/17 finding be interpreted as an accusation against individual Singapore faculty or researchers. The unit of analysis is the public program-content knowledge base. “No evidence identified” means exactly that: the interrogation did not identify substantive public program content establishing the relevant topic as a foundation for quantitative HTA. It does not mean that no individual in Singapore has read Stevens, knows representational measurement, has used Rasch methods or understands scale theory.

But that qualification does not weaken the program-content finding. It strengthens its proper interpretation. A scientific foundation that resides privately in the knowledge of isolated individuals but is not visibly incorporated into the educational and methodological framework cannot perform the function of a scientific foundation for that framework.

The educational consequence is therefore unavoidable. If Singapore wants graduate education in HTA and health economics to claim the standards of quantitative science, measurement cannot remain implicit, assumed or peripheral. It must precede the arithmetic. Students should first be taught attributes, representational measurement, scale properties, admissible transformations, dimensional homogeneity and ratio measurement. They should then distinguish manifest from latent attributes and understand the appropriate measurement route for each. Only after that foundation is secured should utilities, QALYs, ICERs, economic evaluation and modelling be introduced and then as constructs to be tested against measurement requirements rather than accepted in advance.

Singapore's 0/17 versus 20/20 profile consequently represents more than program-content imbalance. It identifies a national quantitative HTA environment in which the methodological superstructure is highly developed while its representational-measurement foundation is not explicitly visible in the public knowledge base reviewed. That is the inversion.

The 20/20 result demonstrates what Singapore has successfully built: an integrated academic and national capability in contemporary HTA. The 0/17 result identifies what should have come first. Once that distinction has been exposed, the appropriate response is not another refinement of economic modelling. It is to ask whether the existing framework can survive when measurement is finally required to precede its arithmetic. Also, because Singapore connects graduate education, HTA research and national healthcare evaluation so closely, the question cannot reasonably be confined to universities. It extends to the entire chain through which quantitative claims acquire authority. If the scientific legitimacy of that chain depends upon lawful measurement, then 0/17 versus 20/20 is not a curriculum curiosity. It is a foundational warning.

CONCLUSION: THE CHALLENGE OF TRANSFORMATION

Now that the measurement problem has been exposed, the challenge facing Singapore universities, research centers, the national HTA environment and the wider health-economics community is substantial. The issue is no longer whether contemporary HTA might benefit from greater attention to measurement theory. The Singapore program-content findings, together with the accompanying evidence of measurement inversion, identify a foundational problem: the central analytical framework of contemporary HTA depends upon arithmetic operations that are inadmissible under the requirements of representational measurement and the standards of normal quantitative science. The measurement cat is now out of the contemporary HTA litter box. It cannot simply be put back.

There is therefore no scientific basis for defending the status quo. The relevant question is no longer whether utilities, QALYs and economic models have proved useful, gained widespread acceptance or been employed for decades in research and healthcare decision-making. Longevity and institutional acceptance do not establish quantitative validity. Nor does incorporation into national technology assessment establish measurement legitimacy. Once the requirements governing admissible arithmetic are applied, the problem becomes transparent. Multiplication requires ratio measurement. Arithmetic operations are constrained by scale properties. Dimensional homogeneity must be maintained. Numerical assignment cannot substitute for measurement. Where these requirements are violated, the resulting arithmetic is inadmissible. No degree of methodological refinement, statistical sophistication, simulation modelling or sensitivity analysis can alter that conclusion.

The challenge for Singapore is therefore one of transformation: how should the Singapore HTA knowledge base be reconstructed to satisfy the requirements of lawful measurement**?** Singapore's universities, research programs and national HTA institutions occupy particularly influential positions within a closely integrated healthcare environment. Through graduate education, methodological research, professional training, health-services research and the activities of the Agency for Care Effectiveness and the wider Ministry of Health environment, quantitative methods move from academic education and research into technology assessment and healthcare decision-making. The 0/17 versus 20/20 program-content finding provides an opportunity to reconsider not simply the content of Singapore HTA and health-economics programs but the scientific sequence in which that content is presented and applied. Measurement must become the foundation upon which subsequent quantitative methods are built rather than an omitted prerequisite.

The starting point is straightforward. Representational measurement must become the organizing scientific principle for HTA rather than an optional addition to existing programs. Students and researchers must first learn to define the target attribute, distinguish manifest from latent attributes, establish the appropriate form of lawful ratio measurement, determine which arithmetic operations are admissible for each scale type, and formulate claims capable of empirical evaluation, replication and falsification. Only after these requirements have been satisfied should further quantitative procedures be considered.

This transformation does not abandon HTA. It places HTA within the accepted standards of normal quantitative science. Singapore's universities, research centers and national HTA institutions therefore face a clear choice: continue reproducing a legacy framework whose arithmetic fails the requirements of representational measurement or lead the reconstruction of HTA around lawful measurement. Given Singapore's international standing in medicine, public health, health-services research, health economics and healthcare policy, together with the close connection between its academic and national decision environments, such a transformation would extend beyond individual courses or institutions. Singapore could demonstrate how a national HTA environment can move from inherited international methodological convention toward a framework in which measurement governs quantitative claims from education through research to healthcare decision-making.

Faculty necessarily have the leading educational role in this transition, while researchers and those responsible for applied HTA have a corresponding responsibility within the wider national environment. This does not imply that investigators or decision-makers have knowingly disregarded representational measurement. Most were themselves educated within the contemporary HTA paradigm and continue to teach, research and apply the methodological framework transmitted through universities, textbooks, journals, professional organizations, international guidelines and established research practice. The 0/17 finding demonstrates the extent to which representational measurement is absent from the publicly presented Singapore program-content knowledge base. Transformation must therefore begin by providing faculty, researchers and practitioners with the scientific knowledge and practical tools required to reconsider the foundations of what they teach and apply. Once measurement failure has been documented, continuing to reproduce it through another generation of graduate students and into subsequent healthcare evaluation is impossible to defend.

It is precisely this gap that the Maimon Research nine-unit transformation program is intended to address [4]. The program is designed as more than a sequence of educational materials. Comprising approximately 45,000 words of structured instructional material, it provides a systematic template for faculty, researchers and practitioners seeking to understand and implement the transition from legacy HTA to a framework grounded in representational measurement. The nine units progress from measurement preceding arithmetic through attributes, scales of measurement, admissible arithmetic and dimensional homogeneity to the distinction between manifest and latent attributes, linear ratio measurement, Rasch measurement, attribute possession and the construction of empirically evaluable therapy-impact claims.

The program can therefore support individual faculty preparation, reconsideration of existing graduate teaching, or development of a new postgraduate course in the organized around lawful measurement and normal science. As far as can presently be ascertained, it is the only program available internationally designed specifically to support the transition from legacy HTA to the new HTA grounded in representational measurement.

An important feature is that participants are not left simply to work through the material independently. Those enrolled have access to continuing 24/7 online Q&A support, both while studying the units and, importantly, as they begin applying the framework in teaching, research and therapy evaluation. Questions concerning particular attributes, proposed measures, Rasch applications, therapy-impact claims, protocols or curriculum development can be raised as they occur. This continuing interaction is particularly important for Singapore faculty whose previous education may not have included representational measurement and who are now reconsidering an HTA framework embedded in international teaching and practice. The objective is not simply completion of nine units but development of the capability to apply the measurement framework independently and introduce it confidently to students and colleagues.

The program can also provide a starting point for broader institutional engagement. Where Singapore universities, research centers, academic departments, HTA groups or professional organizations wish to explore the implications of the new HTA in greater depth, additional activities can be developed around their requirements, including seminars, faculty discussions, workshops, small-group sessions, curriculum-development support and presentations addressing specific measurement or therapy-evaluation problems. This could include engagement with faculty and researchers across the National University of Singapore, Duke-NUS Medical School and associated health-economics, health-services research and quantitative health-research environments**.** These activities allow institutions to move beyond individual enrollment toward reconsideration of how quantitative therapy evaluation is taught, researched and applied.

A fee is charged for access to the nine-unit program to support the maintenance, administration, updating and continuing availability of the system, including participant support. This should not obscure the larger purpose. The objective is transformation: to provide Singapore faculty and institutions with an accessible and supported pathway for replacing the legacy of measurement failure with graduate education grounded in lawful measurement, admissible arithmetic and empirically evaluable claims.

The opportunity is particularly relevant to Singapore because of the close relationship between graduate education, academic research, health-services evaluation and national HTA and healthcare decision-making. A transition beginning within universities need not remain confined to the classroom. Faculty trained in lawful measurement can introduce the framework to students, apply it in research and contribute to a wider reconsideration of the quantitative standards governing therapy evaluation. In a relatively concentrated academic and healthcare environment, the potential exists for a measurement-based approach to move from graduate education through research and ultimately into the wider national evaluation environment.

The nine-unit program is therefore offered as a template for faculty preparation and development of a post-legacy graduate HTA program. Singapore universities do not have to reconstruct the measurement framework independently from first principles. The framework already exists**.** The immediate question is whether faculty and graduate programs are prepared to use it to begin building a new curriculum for the quantitative assessment of therapy impact grounded in lawful measurement, admissible arithmetic and the standards of normal science.

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