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ARTIFICIAL INTELLIGENCE LARGE LANGUAGE MODEL INTERROGATION

REPRESENTATIONAL MEASUREMENT FAILURE IN HEALTH TECHNOLGY ASSESSMENT

NORTH CAROLINA: THE ABSENCE OF REPRESENTATIONAL MEASUREMENT IN HTA RESEARCH CENTER PROGRAMS

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ABSTRACT

Background: *Health technology assessment (HTA) depends upon quantitative claims whose scientific legitimacy requires measurement to precede arithmetic. Scale properties determine admissible mathematical operations, with multiplication and division requiring appropriate ratio properties. Previous interrogations of HTA knowledge bases have identified measurement inversion: extensive application of utilities, QALYs, cost-effectiveness analysis and modelling without prior demonstration of the measurement properties required for their arithmetic.*

Objective: *To assess whether representational measurement is established as the scientific foundation for quantitative HTA, health economics and outcomes research within the publicly available program-content knowledge base of major North Carolina university-affiliated environments.*

Methods: *Publicly available teaching, research, training and methodological content was examined across five environments: the University of North Carolina at Chapel Hill, Duke University, Wake Forest University, East Carolina University and Campbell University. A fixed 37-topic framework, established independently of the North Carolina assessment, comprised 17 topics representing the requirements of representational measurement and 20 representing contemporary health economics and HTA. The unit of analysis was the composite publicly represented knowledge base rather than individual investigators or institutions.*

Results: *The contrast was complete. None of the 17 predetermined representational-measurement topics was explicitly identified as the prior scientific foundation for quantitative claims (**0/17**), whereas all 20 predetermined contemporary health-economics and HTA topics were represented (**20/20**). The latter included economic evaluation, utilities, QALYs, ICERs, cost-effectiveness and cost-utility analysis, patient-reported outcomes, decision modelling, Markov models, simulation and microsimulation, probabilistic sensitivity analysis, value-of-information analysis and budget-impact analysis. The result cannot readily be attributed to lack of quantitative sophistication or sparse program content. Rather, the complete downstream analytical framework is represented without the corresponding upstream measurement framework required to establish whether its arithmetic is admissible.*

Conclusions: *North Carolina provides a particularly stark example of program-content inversion. Students and researchers can encounter the complete predetermined apparatus of contemporary HTA without representational measurement being established as its prior scientific foundation. Reconstruction requires restoration of the correct scientific sequence: attribute definition, measurement requirements, scale determination, admissible arithmetic and only then quantitative claims. Manifest attributes require appropriate linear ratio measurement, while latent attributes require an appropriate measurement model, including Rasch measurement for invariant measurement of defined latent attributes. North Carolina does not lack quantitative sophistication; its challenge is to establish whether the arithmetic it teaches and applies has scientific meaning.*

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 [1] [2] [3] [i] [ii] [iii]. Multiplication and division require appropriate ratio properties; arithmetic must respect admissible transformations and dimensional homogeneity; and manifest and latent attributes require different approaches to measurement.

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 these earlier research-center and program-content assessments by examining a composite North Carolina academic HTA, health-economics and outcomes-research program-content knowledge base. Five university-affiliated environments are included: the University of North Carolina at Chapel Hill, particularly the UNC Eshelman School of Pharmacy health-outcomes, pharmacoeconomic and pharmaceutical-policy environment; Duke University health-economics, medical decision-science, outcomes-research and health-policy environment; Wake Forest University health-services, outcomes and comparative-effectiveness research environment; East Carolina University health-services, clinical-outcomes and economic-evaluation environment; and Campbell University College of Pharmacy & Health Sciences clinical-research, pharmacoeconomic and HEOR environment.

Collectively, these environments encompass health economics, HTA, pharmacoeconomics, economic evaluation, cost-effectiveness and cost-utility analysis, outcomes research, patient-reported outcomes, healthcare value, decision analysis and modelling, simulation, uncertainty analysis, value-of-information analysis, budget impact and health-policy applications. North Carolina therefore provides a substantial academic setting in which to examine whether representational measurement has been incorporated as the scientific foundation for quantitative health evaluation.

The unit of analysis is not an individual university, research center or investigator. It is the publicly available program content through which the composite North Carolina academic HTA, health-economics and outcomes-research knowledge base is expressed and reproduced. This includes teaching and training materials, program and course descriptions, research priorities, methodological statements, projects, publications and other publicly available descriptions of what the included research environments investigate, apply and teach. The purpose is to characterize the North Carolina academic program-content knowledge base rather than to infer what individual faculty members may know, teach informally or address outside that publicly represented framework.

Two contrasting bodies of content are assessed using the fixed 37-topic framework. The first comprises 17 predetermined 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 predetermined topics representing contemporary health economics and HTA, including health economics, HTA, 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. These topics were established in advance and applied consistently; they were not selected or modified in response to the North Carolina knowledge base.

The question is deliberately narrow: does the North Carolina academic HTA, health-economics and outcomes-research 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, statistical analysis and modelling proceed without first establishing that the quantities involved possess the measurement properties required to support the operations performed.

North Carolina provides a demanding test of this proposition. The environments included in the interrogation represent substantial expertise in pharmacy, health economics, pharmacoeconomics, outcomes research, economic evaluation, health policy, decision science and quantitative healthcare research. The issue is therefore emphatically not whether North Carolina universities possess quantitative expertise. They clearly do. Nor is the question whether sophisticated economic, statistical and modelling methods are available. The question is whether representational measurement has been incorporated into this sophisticated academic environment as the governing scientific standard for quantitative claims.

This distinction is fundamental. Representational measurement is not simply another methodology that can be appended to an existing HTA curriculum alongside economic evaluation, econometrics, decision modelling, biostatistics or sensitivity analysis. It establishes the scientific rules governing the admissibility of the arithmetic itself. Once those rules are applied, every numerical construct must satisfy the relevant measurement requirements before subsequent mathematical operations can be justified.

This becomes particularly important where contemporary HTA requires multiplication and division. The existence of a numerical value does not establish ratio measurement, and the desire or requirement to perform a mathematical operation cannot confer upon a number the properties necessary to make that operation admissible. Utilities do not acquire ratio properties because analysts wish to multiply them by time. A QALY does not become a lawful quantity because it is required for a cost-utility model, and an ICER does not become a scientifically meaningful ratio simply because cost per QALY is conventionally reported. The measurement status of the quantities must be established before, rather than inferred from, the arithmetic performed upon them.

The North Carolina review therefore asks whether lawful measurement provides the scientific foundation for its academic HTA, health-economics and outcomes-research program content or whether the inherited analytical framework of contemporary HTA occupies that space without it. The distinction is between two fundamentally different scientific sequences: attribute → measurement requirements → scale → admissible arithmetic → quantitative claim and required analytical output → selected numbers → assumed mathematical properties → arithmetic → modelled claim. The former places measurement before arithmetic. The latter constitutes measurement inversion.

The subsequent interrogation makes the contrast particularly stark. The composite North Carolina knowledge base identifies all 20 of the 20 predetermined topics defining contemporary health economics and legacy HTA. Yet none of the 17 predetermined representational-measurement topics was explicitly established as the prior scientific foundation for that analytical framework.

The resulting 0/17 versus 20/20 profile cannot reasonably be explained by an absence of quantitative expertise or methodological development. Indeed, the completeness of the downstream result makes that explanation particularly implausible. North Carolina demonstrates representation of the entire predetermined contemporary analytical apparatus while providing no identified representation of the upstream measurement requirements necessary to determine whether that apparatus is quantitatively admissible.

For North Carolina universities, this makes the result consequential. These institutions educate future health economists, outcomes researchers, pharmacists, industry scientists, consultants, academics and healthcare decision makers. The question is therefore not confined to the scientific status of current research. It concerns what knowledge is transmitted to the next generation.

If students are taught utilities, QALYs, cost-effectiveness analysis, ICERs, decision models, simulation, uncertainty analysis and value-of-information analysis without first being taught how to establish whether the quantities entering those operations constitute lawful measures, the problem is not simply an incomplete curriculum. The scientific sequence itself has been inverted. A 0/17 versus 20/20 finding in North Carolina therefore does not demonstrate a shortage of quantitative sophistication. It demonstrates that an apparently complete contemporary analytical framework has developed in the wrong scientific order.

FOUNDATIONS OF QUANTITATIVE ANALYSIS

Before examining North Carolina 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 the appropriate ratio properties. 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 HTA and health economics in North Carolina, by contrast, are organized around health economics, pharmacoeconomics, economic evaluation, utilities, QALYs, cost-effectiveness and cost-utility analysis, patient-reported and health outcomes, decision analysis and modelling, simulation, uncertainty analysis, value-of-information analysis, budget impact, healthcare value and policy applications. These methods are represented across major university-affiliated environments at the University of North Carolina at Chapel Hill, Duke University, Wake Forest University, East Carolina University and Campbell University, providing a substantial concentration of expertise in health economics, pharmacoeconomics, outcomes research, HTA, health policy, decision science and quantitative healthcare evaluation.

Institutional acceptance, methodological sophistication and longevity, however, do not determine measurement status. Nor does the reputation of a North Carolina university, college of pharmacy or research center confer measurement properties upon the numbers employed in its analyses. The prior scientific question remains whether the quantities entering those analyses possess the measurement properties required for the arithmetic performed. The fact that utilities, QALYs, ICERs, cost-effectiveness analyses and economic models are well established within North Carolina academic and research environments cannot substitute for demonstrating that their constituent quantities support the mathematical operations required of them.

Indeed, the breadth of contemporary quantitative expertise represented in the North Carolina knowledge base makes the test particularly demanding. The subsequent program-content interrogation identifies all 20 of the 20 predetermined contemporary health-economics and HTA topics. This is therefore not an academic environment in which an absence of representational measurement can readily be attributed to a general lack of methodological development, incomplete program content or quantitative expertise. The predetermined downstream analytical framework is completely represented.

This makes the contrast with representational measurement particularly consequential. A knowledge base capable of representing all 20 predetermined topics of contemporary health economics and HTA provides no identified representation of any of the 17 predetermined representational-measurement topics as the prior scientific foundation governing that analytical framework. The issue is therefore not the extent of quantitative sophistication but the scientific order in which that sophistication has developed.

The North Carolina program-content review therefore asks a straightforward question: does the publicly available North Carolina academic HTA, health-economics and outcomes-research 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? 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 the appropriate ratio properties, 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.

This distinction is particularly important for North Carolina HTA, health economics and outcomes research because its academic knowledge base demonstrates considerable expertise in precisely those methods that depend upon quantitative operations. Economic evaluation, cost-effectiveness analysis, cost-utility analysis, utilities, QALYs, decision analysis and modelling, simulation, uncertainty analysis, value-of-information analysis, patient-reported outcomes, pharmacoeconomics, budget-impact analysis and policy-oriented evaluation are represented across the North Carolina knowledge base. Indeed, the program-content interrogation identifies all 20 of the 20 predetermined contemporary health-economics and HTA topics. The question is therefore not whether North Carolina researchers know how to perform sophisticated quantitative analyses. They clearly do. The question is whether the measurement requirements that determine whether those operations are scientifically admissible have first been established.

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 and the required measurement properties are satisfied, 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. Nor does transforming those scores statistically create the required measurement properties. 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.

The distinction is critical because contemporary health economics and outcomes research frequently treat numerical outputs as though the act of numerical assignment itself establishes quantitative measurement. It does not. A number is not necessarily a measure**.** A preference score does not acquire ratio properties because it is bounded between zero and one. A questionnaire total does not become an interval measure because its items have been added together. A numerical construct does not acquire the properties required for multiplication or division merely because an economic model requires those operations.

The educational requirement can therefore be stated simply. Claims concerning manifest attributes require appropriate 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 through arithmetic, statistical analysis, professional convention, institutional acceptance or incorporation into increasingly sophisticated models.

This ordering is especially important in North Carolina because the academic environments examined at the University of North Carolina at Chapel Hill, Duke University, Wake Forest University, East Carolina University and Campbell University are actively involved in educating future pharmacists, health economists, outcomes researchers, industry scientists, consultants, academics and healthcare decision makers. Once arithmetic is allowed to precede measurement, the analytical framework becomes self-reinforcing. Students learn how to calculate utilities, QALYs and ICERs; researchers refine model structures and parameter estimates; sensitivity and uncertainty analyses become increasingly sophisticated; and the resulting methods acquire legitimacy through repeated academic and professional application. The reputation of the universities and research environments in which these methods are taught can further reinforce that legitimacy. Yet neither methodological sophistication nor institutional reputation answers the logically prior question of whether the quantities being manipulated possess the measurement properties required for those operations.

The North Carolina findings make this problem unusually clear. Across the composite publicly available program-content knowledge base**,** none of the 17 predetermined representational-measurement topics was explicitly identified**,** while all 20 of the 20 predetermined contemporary health-economics and HTA topics were represented. The contrast is therefore not between a poorly developed measurement curriculum and an equally incomplete HTA curriculum. Nor can the result readily be attributed to sparse program content. The entire predetermined downstream analytical framework is represented while the upstream measurement foundation is absent.

Indeed, the completeness of the 20/20 result makes the 0/17 finding more consequential. The North Carolina knowledge base is demonstrably capable of representing the full range of contemporary HTA methods included in the predetermined framework, from economic evaluation, utilities and QALYs through simulation, uncertainty analysis and value-of-information analysis. Yet none of the 17 topics required to establish whether the quantities entering those methods constitute lawful measures is represented as their prior scientific foundation. The asymmetry is therefore systematic rather than incidental.

If representational measurement, scale theory, ratio measurement, admissible transformations, dimensional homogeneity and the distinction between manifest and latent measurement are absent while economic evaluation, utilities, QALYs, cost-effectiveness analysis, patient-reported outcomes, modelling and the remainder of the contemporary HTA framework are comprehensively represented, the result is program-content inversion. North Carolina's 0/17 versus 20/20 profile provides an exceptionally stark example: everything in the predetermined contemporary framework required to perform the arithmetic is represented, while none of the predetermined measurement framework required to determine whether that arithmetic is admissible is represented as its prior scientific foundation.

RATIO MEASUREMENT AND ADMISSIBLE ARITHMETIC

The North Carolina 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, the scale properties demonstrated, and the proposed arithmetic shown to 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. Ratio scales possess both equal units and a non-arbitrary zero and therefore permit meaningful ratio comparisons and the multiplicative arithmetic required for many quantitative claims. Their admissible transformations are similarity transformations of the form $x' = ax$, $a > 0$, under which ratios are preserved. Ratio status is therefore not established merely by the presence of a zero or by assigning numerical values to observations. The required measurement structure must first be demonstrated.

This requirement has immediate consequences for HTA, health economics and outcomes research in North Carolina. 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, costs and other numerical inputs through sequences of arithmetic operations. These methods are extensively represented across the North Carolina academic environments examined.

The scientific question, however, precedes their application: do the quantities entering these operations possess the measurement properties required for the arithmetic performed upon them? Where they do not, the arithmetic is inadmissible. The fact that an operation can be executed mathematically or computationally does not establish that it has empirical meaning. Nor can subsequent statistical analysis, probabilistic sensitivity analysis, modelling or simulation correct a measurement failure that occurred before the arithmetic began. Increasing the sophistication of a model cannot manufacture measurement properties that its inputs do not possess.

The QALY provides the clearest example. Its familiar construction, $\text{QALY} = U \times T$, requires multiplication. Time can satisfy the requirements for linear ratio measurement. The critical question is therefore whether the utility value possesses the measurement properties required to operate as a dimensionless proportional adjustment to time. The need for the multiplication cannot itself confer those properties upon utility. They must be demonstrated independently before the operation is undertaken.

The same principle applies downstream. If the QALY has not been established as a legitimate quantitative measure, subtraction to create an incremental QALY does not repair the problem. Nor can division of incremental costs by an inadmissible ΔQALY create a scientifically meaningful cost-per-QALY ICER. Arithmetic cannot rescue a failure of measurement by adding further arithmetic.

For claims of therapy impact, two measurement pathways are relevant. Manifest attributes require appropriate linear ratio measurement. These include directly observable attributes such as survival time, hospital days, treatment administrations and walking distance where the required unit, zero and measurement properties can be established. Latent attributes including pain, fatigue, physical function and need fulfilment require a different measurement pathway. Rasch measurement provides person-item conjoint measurement, specific objectivity, invariance and a logit continuum for establishing possession of a defined unidimensional latent attribute.

The distinction between these two measurement pathways is fundamental. A manifest attribute cannot simply be treated as though any numerical representation of it were a ratio measure, and a latent attribute does not become a measure because questionnaire responses have been assigned numbers, summed or transformed statistically. Measurement status must be demonstrated rather than assumed.

The North Carolina assessment therefore applies a straightforward criterion. Does the publicly available composite North Carolina academic HTA, health-economics and outcomes-research program-content knowledge base recognize scales of measurement, ratio measurement, admissible transformations, 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 and cost-utility analysis, patient-reported outcomes and decision modelling without first establishing the measurement properties required for their arithmetic?

This question is particularly important because the North Carolina knowledge base represents substantial quantitative expertise. The academic environments examined at the University of North Carolina at Chapel Hill, Duke University, Wake Forest University, East Carolina University and Campbell University collectively encompass health economics, pharmacoeconomics, HTA, economic evaluation, outcomes research, patient-reported outcomes, decision analysis and modelling, simulation, healthcare value, value-of-information analysis, budget-impact analysis and health-policy applications. The issue is not whether these environments possess advanced quantitative expertise. They clearly do. The issue is whether that expertise begins with the scientific requirements governing what can legitimately be quantified and what arithmetic can subsequently be performed.

Ratio measurement is therefore not simply another topic that might usefully be added to a North Carolina HTA, health-economics or outcomes-research curriculum. It establishes a boundary between lawful quantitative analysis and the manipulation of numbers that lack the measurement properties required to support the operations performed upon them.

This is why the absence of ratio measurement from the North Carolina program-content knowledge base is substantially more consequential than the absence of one additional methodological topic. The empirical result is particularly stark: 0/17 representational-measurement topics compared with 20/20 topics defining contemporary health economics and legacy HTA. Unlike Ohio, there is no missing contemporary topic. Students can therefore encounter the complete predetermined analytical framework encompassing health economics, HTA, economic evaluation, utilities, QALYs, cost-effectiveness and cost-utility analysis, ICERs, patient-reported outcomes, decision modelling, simulation and microsimulation, uncertainty analysis, value-of-information analysis and budget-impact analysis without the program-content knowledge base first establishing why multiplication and division require appropriate ratio properties.

The North Carolina result consequently presents the scientific inversion in its most complete form. Everything in the predetermined contemporary framework required to perform the arithmetic is represented; the predetermined measurement framework required to determine whether that arithmetic is lawful is absent**.** Students and researchers are exposed to the downstream analytical apparatus without first being provided with the upstream scientific principles required to interrogate it. Given the substantial concentration of health-economic, outcomes-research and quantitative expertise represented in the North Carolina environments examined, this result cannot readily be explained by lack of methodological sophistication. It instead points to the organization of the knowledge base itself.

Indeed, the 20/20 result makes the **0/17** finding more, rather than less, consequential. The North Carolina knowledge base is demonstrably capable of representing the entire predetermined contemporary HTA framework. Its failure to represent any of the 17 predetermined topics establishing the measurement foundation cannot therefore readily be dismissed as the consequence of sparse program content. The asymmetry is complete and systematic: comprehensive representation of downstream methods is accompanied by complete absence of the upstream measurement requirements that determine whether those methods are quantitatively admissible.

For North Carolina, therefore, the program-content interrogation asks a foundational rather than merely methodological question. Across major university-affiliated health-economics, pharmacoeconomic and outcomes-research environments, are researchers and students being taught first how to measure, or first how to manipulate the numbers required by the inherited HTA framework? The distinction is between measurement determining admissible arithmetic and required arithmetic determining presumed measurement properties. It is the distinction between measurement preceding arithmetic and arithmetic preceding measurement, and it is the distinction upon which the North Carolina program-content assessment rests.

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 probabilities of endorsement, it examines whether specified scientific and methodological topics are explicitly represented in the publicly available program content of the Ohio academic HTA, health-economics and outcomes-research knowledge base**.**

The Ohio knowledge base comprises publicly accessible teaching, research and training content associated with four major university-affiliated research and educational environments: the Ohio State University Center for Health Outcomes and Policy Evaluation Studies (HOPES); the Ohio State University College of Pharmacy outcomes and pharmacoeconomic research environment; the University of Cincinnati Health Outcomes and Pharmacoeconomics research and graduate environment; and the University of Toledo Health Outcomes and Value Analytics/Health Outcomes and Socioeconomic Sciences environment. Material considered includes program and course descriptions, research priorities, methodological statements, projects, publications, seminars and training activities. The objective is not to evaluate individual investigators, courses or institutions, but to characterize the composite Ohio academic HTA, health-economics and outcomes-research program-content knowledge base.

Two contrasting groups of content are examined using a fixed 37-topic framework. The first comprises 17 topics representing representational measurement, including measurement preceding arithmetic, scales of measurement, axioms of representational measurement, ratio measurement, admissible transformations and arithmetic, dimensional homogeneity, manifest and latent attributes, linear ratio measurement and Rasch measurement.

The second comprises 20 topics representing contemporary health economics and HTA, including economic evaluation, cost-effectiveness and cost-utility analysis, pharmacoeconomics, utilities, QALYs, ICERs, patient-reported outcomes, decision analysis, Markov and simulation modelling, uncertainty analysis, value-of-information analysis, budget impact and value assessment.

The interrogation asks a single question: does the Ohio academic HTA, health-economics and outcomes-research program-content knowledge base establish representational measurement as the foundation for quantitative claims before presenting or applying the analytical methods of contemporary HTA?

A topic is classified as explicitly represented where identifiable public evidence demonstrates its presence within the research, teaching or methodological knowledge base. Failure to identify such evidence is reported as “No evidence identified.” This does not imply that individual Ohio researchers are unfamiliar with the topic. It means that the topic was not identified as part of the publicly represented program-content framework examined.

Importantly, references to *measurement*, *outcome measurement*, *preference measurement*, *health-state measurement* or *psychometrics* do not by themselves establish recognition of representational measurement. Similarly, numerical ratios, bounded values or values incorporating a zero do not establish recognition of ratio measurement. The criterion is whether the measurement principles themselves, and their implications for admissible arithmetic, are explicitly represented. This distinction is particularly important in an HTA environment in which numerical health-state valuation and patient-reported outcomes may routinely be described as measurement without demonstrating the representational properties required to justify that description.

If representational measurement is absent while contemporary HTA methods 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 scientific framework determining whether those operations are admissible.

The Ohio assessment therefore asks whether lawful measurement provides the scientific foundation for quantitative HTA or whether the legacy HTA framework is represented without the measurement standards required to establish the admissibility of its arithmetic. Given the breadth and methodological sophistication of the environments examined, Ohio provides a demanding test of that question. These are not environments lacking quantitative expertise; collectively they represent substantial expertise in health economics, HTA, pharmacoeconomics, economic evaluation, cost-effectiveness and cost-utility analysis, outcomes research, patient-reported outcomes, decision modelling, simulation, budget-impact analysis, healthcare value and health-policy applications.

The significance of the test is therefore straightforward. If an Ohio academic knowledge base capable of representing 19 of the 20 predetermined analytical topics of contemporary health economics and HTA does not explicitly represent any of the 17 predetermined topics establishing the scientific requirements of representational measurement, the issue **cannot** readily be attributed to a lack of quantitative sophistication. It identifies the absence of the scientific measurement framework that should logically precede and govern that sophistication.

The resulting 0/17 versus 19/20 comparison therefore provides the empirical test of program-content inversion in Ohio: an almost complete representation of the downstream analytical framework accompanied by no identified representation of the upstream measurement requirements needed to determine whether its quantitative operations are admissible.

ASSESSMENT RESULTS: PROGRAM CONTENT REVIEW

Jurisdiction: North Carolina, United States

Knowledge Base: North Carolina Academic Health Technology Assessment, Health Economics and Outcomes Research Knowledge Base (Program Content)

University-affiliated environments

1. University of North Carolina at Chapel Hill — UNC Eshelman School of Pharmacy / health outcomes, pharmacoeconomics and pharmaceutical-policy environment
2. Duke University — health economics, medical decision science, outcomes research and health-policy environment
3. Wake Forest University — health-services, outcomes and comparative-effectiveness research environment
4. East Carolina University — health-services, clinical outcomes and economic-evaluation environment
5. Campbell University — College of Pharmacy & Health Sciences / clinical research, pharmacoeconomics and HEOR environment

The unit of analysis is the composite publicly available North Carolina program-content knowledge base, not the private knowledge of individual investigators. The criterion is whether representational measurement is explicitly established as the scientific foundation for quantitative claims before contemporary HTA and health-economic methods are introduced, researched, taught or applied.

TABLE 1: REPRESENTATIONAL MEASUREMENT

Topic	Explicitly recognized	North Carolina program evidence
Representational measurement	No evidence identified	—
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	—

Topic	Explicitly recognized	North Carolina program evidence
Two admissible ratio measures for therapy impact	No evidence identified	—

RESULT: 0/17

No topic from the fixed 17-topic representational-measurement framework was explicitly identified as providing the prior scientific foundation for quantitative HTA claims within the publicly represented North Carolina knowledge base reviewed.

This finding requires the same qualification we used for Ohio. North Carolina researchers certainly use the language of *measurement*. Outcomes research, health-status assessment, patient-reported outcomes, utility estimation, preferences, quality of life and psychometric assessment can all be described using measurement terminology. That was not sufficient for inclusion.

The criterion is narrower: explicit recognition that an attribute must first be defined and measured; that the scale achieved determines admissible transformations and arithmetic; that multiplication and division require appropriate ratio properties; that dimensional homogeneity constrains permissible operations; and that manifest and latent attributes require different measurement pathways.

The targeted searches also did not identify evidence that isolated references to Rasch methods, psychometrics or scale terminology have been incorporated into the North Carolina HTA/HEOR knowledge base as the organizing scientific foundation governing downstream quantitative analysis. On the predetermined criterion, the result is therefore 0/17.

TABLE 2: CONTEMPORARY HEALTH ECONOMICS AND HTA FRAMEWORK

Topic	Explicitly represented	North Carolina program evidence
Health economics	Yes	UNC, Duke and the wider academic knowledge base explicitly represent health-economic analysis
Health technology assessment	Yes	HTA explicitly represented in UNC-affiliated cost-utility/technology-assessment research and the broader decision environment
Economic evaluation	Yes	Economic evaluation and intervention cost analysis represented particularly strongly at Duke and UNC
Cost-effectiveness analysis	Yes	Extensive evidence across Duke, UNC, Wake Forest, ECU and Campbell

Topic	Explicitly represented	North Carolina program evidence
Cost-utility analysis	Yes	Explicit CUA and QALY-based evaluations represented in the composite knowledge base
Pharmacoeconomics / pharmaceutical economic evaluation	Yes	UNC Eshelman and Campbell pharmacy environments explicitly represent pharmacoeconomic/HEOR activity
Utilities and preference-based outcomes	Yes	Duke explicitly represents utility/preference measurement; utility-based economic evaluations also occur elsewhere
Quality-adjusted life-years (QALYs)	Yes	QALYs explicitly employed in North Carolina-affiliated economic evaluations
Incremental cost-effectiveness ratios (ICERs)	Yes	Cost/QALY and ICER analyses explicitly represented
Measurement and valuation of health outcomes / patient-reported outcomes	Yes	Outcomes, quality-of-life, patient-reported and preference research extensively represented
Decision analysis	Yes	Duke explicitly represents decision-analytic modelling
Decision-tree modelling	Yes	Decision-analytic economic modelling represented within the composite research environment
Markov modelling	Yes	Explicit Markov models at Duke, Wake Forest and ECU/Duke-associated economic evaluations
Simulation and microsimulation modelling	Yes	Simulation and microsimulation explicitly represented in North Carolina-affiliated research
Probabilistic sensitivity and uncertainty analysis	Yes	PSA and uncertainty analysis explicitly represented in cost-effectiveness research
Value-of-information analysis	Yes	Duke-affiliated research explicitly applies VOI/EVPI methods
Budget-impact analysis	Yes	Duke explicitly identifies budget-impact analysis among its health-economic research methods
Healthcare priority setting and resource allocation	Yes	Duke health-policy and CEA environments explicitly link economic evaluation to allocation decisions
Value-for-money / value assessment	Yes	Cost-effectiveness, healthcare value and willingness-to-pay/value frameworks represented

Topic	Explicitly represented	North Carolina program evidence
Policy, reimbursement and decision use of economic evaluation	Yes	Duke, UNC and other environments connect economic and outcomes evidence with healthcare decision making

RESULT: 20/20

The contemporary side of the North Carolina knowledge base is comprehensively represented.

Duke provides particularly strong evidence. Its public health-economic environment explicitly identifies cost-effectiveness analysis, decision-analytic modelling, budget-impact analysis and utility/preference measurement. Duke also has extensive QALY, ICER and Markov-model research: its Second Panel activity explicitly concerns methods and standards for cost-effectiveness analysis, while individual Duke research demonstrates Markov modelling, QALYs, ICERs and probabilistic sensitivity analysis.

Crucially, value-of-information analysis is explicitly represented, eliminating the single gap found in Ohio. Duke-affiliated research reports expected value of perfect information and uses VOI to determine the value of further research. This means there is no justification for scoring VOI absent in the North Carolina composite knowledge base.

UNC contributes particularly strong evidence for cost-utility analysis, HTA, QALYs and ICERs. UNC Eshelman-affiliated work explicitly describes cost-utility analysis as widely used in HTA and evaluates cost-effectiveness thresholds in relation to ICERs and QALYs. UNC-affiliated research also includes intervention cost-effectiveness evaluation.

Wake Forest contributes economic evaluation and modelling evidence. Wake Forest-affiliated work includes Markov-model cost-effectiveness analysis, microsimulation cost-effectiveness analysis, and current cost-effectiveness research in healthcare technologies.

East Carolina contributes health-outcomes and economic-evaluation evidence. ECU publicly identifies health-outcomes research and evaluation of clinical and economic outcomes, while ECU-affiliated economic evaluations include cost-utility analysis employing Markov modelling.

Campbell adds the pharmacy, pharmacoeconomic and HEOR component. Its academic material explicitly identifies health economics and outcomes research as a career and research area, its pharmacy curriculum has explicitly included advanced pharmacoeconomics, and its clinical-research faculty have presented specifically on cost-effectiveness analysis.

OVERALL NORTH CAROLINA RESULT

The result is therefore:

Representational measurement: 0/17

Contemporary health economics and HTA: 20/20

The North Carolina university affiliated environments provide particularly strong evidence of contemporary HEOR and HTA program content. The University of North Carolina at Chapel Hill contributes health economics, pharmacoeconomics, economic evaluation, utilities, QALYs, cost-effectiveness and outcomes research. Duke University adds an extensive health-economic and decision-science environment encompassing cost-effectiveness analysis, utility assessment, decision modelling, budget-impact analysis and value-of-information analysis. Wake Forest University, East Carolina University and Campbell University provide additional evidence through health-services and outcomes research, economic evaluation, pharmacoeconomics, modelling and related quantitative methods.

The interrogation also identified explicit North Carolina research applications of QALY-based economic evaluation, ICERs, decision trees and Markov models, simulation and microsimulation, probabilistic sensitivity analysis, budget-impact analysis and value-of-information analysis. These findings extend the evidence beyond descriptions of the five university-affiliated environments themselves and demonstrate an established downstream quantitative research architecture.

ASSESSMENT OF NORTH CAROLINA RESULTS

The North Carolina result is not a marginal curriculum imbalance. It is not evidence that a few topics in measurement theory might usefully be added to an otherwise scientifically coherent health technology assessment and health-economics framework. The contrast is too complete for that interpretation. Across the composite publicly available program-content knowledge base of the five university-affiliated environments examined, all 20 predetermined topics defining contemporary health economics and legacy HTA are represented, while none of the 17 predetermined topics establishing the requirements of representational measurement is explicitly represented as their prior scientific foundation. The result is 0/17 versus 20/20. That is program-content inversion in its starkest form.

North Carolina plainly does not lack quantitative sophistication. The environments examined encompass health economics, pharmacoeconomics, economic evaluation, cost-effectiveness and cost-utility analysis, utilities, QALYs, ICERs, patient-reported outcomes, decision analysis, Markov modelling, simulation, uncertainty analysis, value-of-information analysis, budget-impact analysis, healthcare value and policy applications. The entire predetermined downstream analytical apparatus is represented. The problem is therefore almost precisely the reverse of methodological underdevelopment. A sophisticated analytical superstructure has been constructed and transmitted without the publicly represented measurement foundation required to determine whether its central quantitative operations are scientifically admissible.

The missing material is not decorative. Representational measurement determines whether numbers constitute measures in the first place. Scale properties determine which transformations and arithmetic operations preserve empirical meaning. Ratio properties are required where multiplication, division and ratio comparisons are claimed. Dimensional homogeneity constrains which quantities may legitimately be combined. Manifest and latent attributes require different measurement pathways. These requirements are logically prior to economic evaluation, statistical analysis and modelling. Yet the North Carolina knowledge base represents everything in the predetermined framework required to perform contemporary HTA while representing none of the predetermined framework required to establish whether its arithmetic is lawful.

The QALY exposes the problem immediately. Students and researchers can encounter utilities, QALYs, cost-utility analysis and cost-per-QALY ICERs. But the 0/17 finding identifies no corresponding program-content foundation requiring the prior questions to be answered: what attribute does the utility measure? Is that attribute unidimensional? What measurement structure has been demonstrated? What scale has been achieved? What establishes a non-arbitrary zero and equal units? What authorizes interpreting the utility as a dimensionless proportional adjustment to time? The fact that U can be multiplied by T computationally does not establish that U × T has empirical meaning.

Everything that follows inherits the problem. If the QALY has not first been established as a lawful quantitative measure, subtraction does not rescue it by producing an incremental QALY. Division does not rescue it by producing a cost-per-QALY ICER. A Markov model does not rescue it. Microsimulation does not rescue it. Probabilistic sensitivity analysis does not rescue it. Value-of-information analysis does not rescue it. Indeed, the North Carolina 20/20 result makes the problem more severe: every additional layer of downstream sophistication magnifies rather than repairs the consequences of failing to pass the measurement gate.

This raises an unavoidable educational question. What exactly are universities teaching when students can master the complete apparatus of contemporary HTA without first being required to establish whether the quantities entering that apparatus are measures? Technical proficiency cannot substitute for scientific legitimacy. Nor can professional acceptance, publication volume, institutional reputation or methodological complexity confer measurement properties upon numbers that do not possess them. Repeating an arithmetic operation across thousands of models does not transform an inadmissible operation into an admissible one.

Faculty may reasonably respond that they inherited this framework. They were themselves educated through universities, textbooks, journals, professional organizations and methodological standards in which representational measurement was not established as the gatekeeper for quantitative claims. That explains how program-content inversion could become entrenched. It cannot justify transmitting it again. Once the measurement failure has been exposed, another generation of North Carolina students cannot simply be taught utilities, QALYs, ICERs and increasingly sophisticated models as though the scientific challenge had never been raised.

Nor is the solution to add a lecture on scales of measurement to an otherwise unchanged curriculum. The 0/17 versus 20/20 result demonstrates that the problem concerns ordering. The architecture itself is inverted. Attribute definition must precede measurement. Measurement must precede arithmetic. Scale properties must determine admissible operations. Manifest attributes require appropriate linear ratio measurement; latent attributes require an appropriate measurement model, including Rasch measurement where invariant measurement of a defined latent attribute is sought. Only quantities surviving that measurement gate should proceed to downstream quantitative analysis.

North Carolina universities therefore face a choice. They can defend the existing framework by demonstrating that its central quantitative constructs possess the measurement properties their arithmetic requires. Convention is not that demonstration. Professional consensus is not that demonstration. A reference case is not that demonstration. The fact that software produces an answer is certainly not that demonstration. The required properties must be established scientifically.

If they cannot be established, reconstruction follows. This is not methodological vandalism and it is not abandonment of quantitative therapy evaluation. It is precisely the opposite. It is the restoration of the scientific sequence that quantitative evaluation should have followed from the outset.

The North Carolina finding is therefore exceptionally difficult to explain away. The contemporary framework scores 20/20. There is no missing downstream topic behind which the result can hide. The representational-measurement framework scores 0/17. The contrast could scarcely be clearer: everything required to manipulate the numbers is represented; nothing in the predetermined measurement framework required to establish whether those manipulations are lawful is represented as their scientific foundation.

North Carolina does not need more sophisticated arithmetic. It needs to establish whether the arithmetic it already teaches and applies has scientific meaning.

Measurement must precede arithmetic. Until that requirement becomes the organizing principle of North Carolina HTA, health economics and outcomes research, the 0/17 versus 20/20 profile stands as evidence of a knowledge architecture that is not merely incomplete but scientifically inverted.

CONCLUSION: NORTH CAROLINA TRANSITION TO LAWFUL MEASUREMENT

Now that the measurement problem has been exposed, the challenge facing North Carolina universities, research centers and the wider HTA and health-economics community is substantial. The issue is no longer whether contemporary HTA might benefit from greater attention to measurement theory. The North Carolina program-content findings, together with the accompanying evidence of measurement and program-content inversion, identify a foundational problem: the central analytical framework of contemporary HTA depends upon arithmetic operations whose admissibility has not first been established under the requirements of representational measurement and the scales of measurement. 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 simply by appealing to established American or international practice. The relevant question is no longer whether utilities, QALYs, cost-effectiveness models and related methods have proved useful, achieved widespread professional acceptance or been employed for decades in research, reimbursement and healthcare decision-making. Longevity, institutional acceptance and methodological sophistication do not establish quantitative validity. Once the requirements governing admissible arithmetic are applied, the problem becomes transparent. Multiplication and division require the appropriate ratio properties. 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 statistical sophistication, simulation modelling, uncertainty analysis or methodological refinement can repair a measurement failure that occurs before the arithmetic begins.

The challenge for North Carolina is therefore one of transformation: how should established academic environments for health economics, pharmacoeconomics, outcomes research and healthcare evaluation be reconstructed to satisfy the requirements of lawful measurement?

The five environments included in the present interrogation—the University of North Carolina at Chapel Hill, particularly the UNC Eshelman School of Pharmacy health-outcomes, pharmacoeconomic and pharmaceutical-policy environment; Duke University health-economics, medical decision-science, outcomes-research and health-policy environment; Wake Forest University health-services, outcomes and comparative-effectiveness research environment; East Carolina University health-services, clinical-outcomes and economic-evaluation environment; and Campbell University College of Pharmacy & Health Sciences clinical-research, pharmacoeconomic and HEOR environment—represent a substantial concentration of quantitative healthcare expertise. Through graduate education, research, professional training and collaboration with healthcare, industry and policy communities, these environments contribute to the analytical framework applied within and beyond North Carolina.

The **0/17 versus 20/20** program-content finding therefore provides an opportunity to reconsider not simply what is included in North Carolina academic HTA and health economics, but the scientific sequence in which that knowledge is organized. The contrast could scarcely be more complete. All twenty predetermined topics defining contemporary health economics and legacy HTA are explicitly represented, while none of the seventeen predetermined topics defining representational measurement is explicitly established as the scientific foundation upon which those methods depend. North Carolina does not lack quantitative sophistication. The problem is almost precisely the reverse: it possesses a highly developed analytical superstructure without the publicly represented measurement foundation required to establish whether its central operations are quantitatively admissible.

This makes the North Carolina result particularly difficult to dismiss. The contemporary knowledge base is sufficiently developed to represent **the** entire predetermined downstream analytical framework**.** Unlike Ohio, there is no missing contemporary topic. The 0/17 finding cannot therefore readily be attributed to an academically immature environment, sparse program content or an absence of quantitative methods. The environments examined possess substantial expertise in health economics, pharmacoeconomics, outcomes research, economic evaluation, patient-reported outcomes, modelling, value-of-information analysis and health-policy applications. The absence of representational measurement instead points directly to the scientific organization of the knowledge base itself.

The starting point for reconstruction is straightforward. Representational measurement must become the organizing scientific principle for quantitative therapy evaluation rather than an optional supplement to the existing HTA curriculum. Students and researchers must first learn to identify and define the target attribute, establish unidimensionality, distinguish manifest from latent attributes, determine the appropriate measurement pathway, establish the scale achieved and identify the arithmetic operations admissible for that scale. They must understand why multiplication and division impose ratio requirements, why dimensional homogeneity matters and why assigning numbers to health states, questionnaire responses or preferences cannot manufacture measurement properties that have not been demonstrated empirically.

For manifest attributes, the appropriate pathway is linear ratio measurement. For latent attributes, the alternative is Rasch measurement, with its requirements for conjoint measurement, invariance and specific objectivity. These two measurement pathways provide the foundation for constructing attribute-specific therapy-impact claims that can be empirically evaluated, replicated and potentially falsified. Only after these measurement requirements have been satisfied should arithmetic, statistical analysis, economic evaluation or other quantitative procedures be undertaken. These are not novel standards created in response to contemporary HTA. The underlying requirements of measurement and scale-dependent arithmetic have been part of quantitative science for decades.

The required transformation does not abandon HTA. It rescues therapy evaluation from a legacy analytical framework and places it within the accepted standards of normal quantitative science.

North Carolina universities and research centers therefore face a clear choice. They can continue reproducing an inherited framework of measurement failure in which utilities, QALYs, ICERs and modelled claims are accepted without first demonstrating that their constituent quantities support the arithmetic required of them. Or they can begin the reconstruction of quantitative therapy evaluation around defined attributes, lawful measurement, admissible arithmetic and empirically evaluable claims.

The North Carolina environments examined do not operate in methodological isolation. Their faculty educate future pharmacists, health economists, outcomes researchers and other healthcare professionals; publish research; collaborate with pharmaceutical manufacturers, healthcare organizations and policy communities; and contribute to the wider development and application of quantitative healthcare methods. The scientific standards governing measurement cannot change according to institutional prestige or professional influence. The same requirements must apply whether a quantitative claim originates at UNC-Chapel Hill, Duke, Wake Forest, East Carolina, Campbell, another university, a pharmaceutical manufacturer, an HTA organization or a government agency. Institutional authority cannot confer measurement properties upon numbers that do not possess them.

Faculty necessarily have the leading educational role in this transition. This does not imply that North Carolina investigators have knowingly disregarded representational measurement. Contemporary faculty were themselves largely educated within the established health-economics and HTA paradigm. They learned the methods transmitted through universities, textbooks, journals, professional organizations, methodological guidelines and accepted research practice. If representational measurement and the arithmetic of scales of measurement were absent from that education, there was little reason for investigators subsequently to recognize that the arithmetic they had inherited rested upon measurement assumptions that had never been demonstrated.

The North Carolina **0/17** finding demonstrates how complete that omission remains within the publicly represented program-content knowledge base. It helps explain how the legacy could have been transmitted from one generation of researchers to another. It cannot justify transmitting it again.

Once the measurement problem has been explicitly identified, faculty and universities acquire a different responsibility. Students entering North Carolina health-economics, HTA, pharmacoeconomics and outcomes-research programs should not simply be trained to reproduce methods because those methods are professionally established. They should be given the scientific knowledge necessary to determine whether those methods are quantitatively admissible. Faculty who believe that utilities support multiplication by time, that QALYs constitute legitimate quantitative measures, or that cost-per-QALY ICERs possess the properties attributed to them should be entirely free to defend those propositions. But students must equally be provided with the principles of representational measurement and scale theory necessary to determine whether those propositions can be sustained.

This is where the 20/20 finding becomes particularly uncomfortable**.** The North Carolina academic knowledge base is demonstrably capable of providing students with the complete predetermined methodological apparatus of legacy HTA. Students can encounter economic evaluation, utilities, QALYs, cost-effectiveness and cost-utility analysis, ICERs, patient-reported outcomes, decision trees, Markov models, simulation and microsimulation, probabilistic sensitivity analysis, value-of-information analysis and budget-impact analysis. It therefore cannot reasonably be argued that introducing the scientific principles required to interrogate that apparatus is beyond the educational capacity of these institutions. If students can master the downstream sophistication, they can certainly master the upstream measurement principles that determine whether the downstream arithmetic is lawful.

The question is one of priority.

This creates a particular responsibility for universities. A university is not simply a mechanism for reproducing prevailing professional practice. Its responsibility is to expose established claims and methods to critical scientific scrutiny. Academic freedom protects faculty who wish to defend conventional utilities, QALYs, ICERs and reference-case modelling. It equally requires an intellectual environment in which students are provided with the scientific principles necessary to challenge them. The appropriate university response to a foundational criticism is not to determine in advance which side must prevail. It is to ensure that students possess the knowledge necessary to evaluate the competing claims.

The implications for students are therefore immediate. Graduate students invest substantial time and resources in their education and may subsequently spend decades applying the methods they have been taught. They are entitled to expect more than technical proficiency in an inherited analytical framework. They should understand the scientific conditions under which quantitative claims are possible and be capable of determining whether those conditions have been met.

The responsibility becomes still more difficult now that the challenge is publicly available. Another generation of students cannot simply be introduced to the same analytical framework as though no measurement problem had been identified. Universities and faculty do not have to endorse the critique. They do not have to accept the conclusion that the QALY or the cost-per-QALY reference case fails representational-measurement requirements. But they should expose students to the principles necessary to decide that question for themselves.

Otherwise, the question that may eventually be directed back at today's faculty is straightforward: Why were we taught how to construct utilities, QALYs, ICERs and increasingly sophisticated models, but never taught the measurement principles required to determine whether those operations were scientifically admissible when those principles and the challenge they posed were already available?

That is not a question that can satisfactorily be answered by pointing to established practice, professional consensus or the reputation of the institution that provided the education.

Transformation must therefore begin with faculty. North Carolina universities and research centers need to introduce the scientific knowledge and practical tools required for faculty themselves to reconsider the measurement foundations of what they research and teach. This cannot be accomplished merely by inserting an isolated lecture on measurement into an otherwise unchanged curriculum. Once students understand that measurement precedes arithmetic, the implications extend throughout economic evaluation, utility measurement, QALY construction, cost-effectiveness analysis, outcomes measurement and decision modelling. Measurement cannot be taught seriously and then quarantined from the methods it calls into question.

The route out is nevertheless surprisingly straightforward. It requires neither another economic model nor another refinement of the reference case. It requires restoration of the scientific sequence that legacy HTA abandoned: science demands measurement, not merely numbers. Identify the attribute; establish its measurement requirements; determine whether it is manifest or latent; construct the appropriate measure; establish the arithmetic permitted by that measure; and then formulate therapy-impact claims that are empirically evaluable, replicable and capable of falsification.

The 0/17 versus 20/20 finding should consequently be treated not as a criticism of North Carolina quantitative expertise but as a warning about its scientific foundations. North Carolina has developed a substantial infrastructure for contemporary health economics, pharmacoeconomics, outcomes research and HTA. What is now required is an equally serious commitment to establishing whether the numbers manipulated within that infrastructure are measures and whether the arithmetic performed upon them is lawful.

North Carolina also has an opportunity. Its universities do not need to wait for ISPOR, an HTA agency or another central authority to reconstruct the scientific foundations of what they teach. The requirements of representational measurement already exist, and the transition can begin within individual academic and research environments. The fact that the inherited framework is internationally established does not require North Carolina universities to continue reproducing it once its measurement foundations have been challenged.

The choice is therefore straightforward. North Carolina can continue reproducing an inherited legacy HTA paradigm in which arithmetic precedes demonstrated measurement, or its universities can help lead the transition to a post-legacy framework in which measurement precedes arithmetic, ratio properties precede multiplication and division, and empirically evaluable claims replace assumption-driven numerical storytelling.

The measurement problem has been identified. The scientific standards are available. The alternative measurement framework is available. The remaining question is whether another generation of North Carolina students will be taught the legacy as though none of this had happened.

It is precisely this challenge that the Maimon Research nine-unit transformation program is intended to address [4]. This program provides a structured template for faculty, researchers and practitioners seeking to understand and implement the transition from the measurement failure of legacy HTA to a framework grounded in representational measurement. The program comprises 45,000 words of structured instructional material with the nine units moving progressively 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 be used for individual faculty preparation, as a framework for reconsidering existing graduate teaching, or as the foundation for developing a new postgraduate course in HTA organized around the requirements of lawful measurement and normal science.

The material presented can be integrated into existing programs without requiring wholesale curriculum reconstruction. The essential change is one of scientific sequence. At the beginning of a course, students should be provided with the measurement principles required to interrogate every quantitative method that follows: what is the attribute to be measured; is it unidimensional; is it manifest or latent; what measurement scale has been established; what transformations and arithmetic are admissible; and does the proposed analysis preserve dimensional homogeneity? These questions can then be applied systematically as students encounter utilities, QALYs, reference case economic evaluation, patient-reported outcomes, decision models and the other established components of legacy HTA.

Representational measurement thereby becomes not another topic added to an already crowded curriculum but the organizing scientific framework through which the existing curriculum is critically assessed. Importantly, this places students in a position to judge the merits of the alternatives for themselves: whether there is a defensible scientific basis for continuing to support the legacy HTA framework, or whether quantitative therapy evaluation should instead be reconstructed around lawful measurement, admissible arithmetic, evaluable claims, replication and falsification; the standards expected of normal science. The educational responsibility is therefore not to prescribe the conclusion students must reach, but to ensure that they possess the scientific knowledge required to make that judgment.

An important feature of the program is that participants are not left simply to work through the material independently. Those enrolled have access to continuing 24/7 on line Q&A support from

Maimon Research as they study the units and, importantly, as they begin to apply the framework in teaching, research or therapy evaluation**.** Questions arising from particular attributes, proposed measures, Rasch applications, therapy-impact claims, protocols or curriculum development can be raised as they occur. The purpose is to support the transition from understanding the principles to applying them in practice. This continuing interaction is particularly important for faculty whose previous education did not include representational measurement and who may be reconsidering assumptions embedded in many years of teaching and research. The objective is not simply completion of nine units, but development of the capability to use the measurement framework independently and to introduce it confidently to students and colleagues.

The program can also provide a starting point for broader institutional engagement. Where universities, research centers, academic departments or professional groups wish to explore the implications of the new HTA in greater depth, additional activities can be developed around their particular requirements, including seminars, faculty discussions, workshops, small-group sessions, curriculum-development support and presentations addressing specific measurement or therapy-evaluation problems. These activities allow institutions to move beyond individual enrollment toward a wider reconsideration of how HTA is taught 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. The larger objective, however, is transformation: to provide faculty and institutions with an accessible, supported pathway for replacing the legacy of measurement failure with graduate education grounded in lawful measurement, admissible arithmetic and empirically evaluable claims.

The nine-unit program is therefore offered as a template for faculty preparation and the development of a post-legacy graduate HTA program. Universities may use the framework to reconsider existing teaching or as the foundation for constructing a new graduate course organized explicitly around representational measurement

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