Linear units improve articulation between social and physical constructs: An example from caregiver parameterization for children supported by complex medical technologies

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Abstract. Despite broad sweeping pronouncements by international research organizations that social sciences are being integrated into global research programs, little attention has been directed toward obstacles blocking productive collaborations. In particular, social sciences routinely implement nonlinear, ordinal measures, which fundamentally inhibit integration with overarching scientific paradigms. The widely promoted general linear model in contemporary social science methods is largely based on untransformed scores and ratings, which are neither objective nor linear. This issue has historically separated physical and social sciences, which this report now asserts is unnecessary. In this research, nonlinear, subjective caregiver ratings of confidence to care for children supported by complex, medical technologies were transformed to an objective scale defined by logits (N=70). Transparent linear units from this transformation provided foundational insights into measurement properties of a social-humanistic caregiving construct, which clarified physical and social caregiver implications. Parameterized items and ratings were also subjected to multivariate hierarchical analysis, then decomposed to demonstrate theoretical coherence (R² >.50), which provided further support for convergence of mathematical parameterization, physical expectations, and a social-humanistic construct. These results present substantial support for improving integration of social sciences with contemporary scientific research programs by emphasizing construction of common variables with objective, linear units.

1. Introduction
Since the 1980s, organizations such as the National Academy of Sciences, US Global Change Research Program, International Social Science Council, and International Geosphere-Biosphere Program among others have emphasized social and physical science collaboration to address international research problems. Growing recognition that social forces are a dominant contributor to global warming, oceanic pollution, and international terrorism emphasizes mobilization of social and physical science collaboration to solve international problems. Despite early disappointments, progress toward collaboration continues and today several initiatives such as the Intergovernmental Platform on Biodiversity and Ecosystem Services, as well as ongoing basic and applied science programs integrate physical and social sciences [1, 2].
2. Problem
Despite broad consensus about collaboration benefits to scientific problem solving, and enormous strides toward establishing organizational infrastructure, social scientists express deep frustration with institutionalized organizational barriers, as well as entrenched social attitudes against physical and social science integration [3]. In general, social and physical collaborations tend to display asymmetrical relations. Not surprisingly, social scientists are calling for more meaningful collaboration with physical science initiatives and specifically greater access to decision making and research policy [4].

While these complaints are certainly legitimate, social scientists demonstrate little recognition of their own dysfunctional role in blocking advances toward meaningful collaboration. The social sciences typically maintain incommensurable paradigms, divergent epistemologies, as well as incompatible ontologies, which has led to their marginalization in scientific policy and governance. At a practical level, lack of a common language or complementary methodology creates enormous barriers to collaboration with physical sciences. Not surprisingly, the social sciences are commonly viewed as intellectually provincial outposts on the outskirts of scientific knowledge. A goal of this research is to show this general bifurcation into social and physical sciences is no longer necessary.

3. Objective
Genuine efforts to improve physical and social science collaboration have turned to mutual benefits derived from shared empirical methods. For example, correlational statistical methods originally developed by the social sciences, now provide a venue for convergence between otherwise disparate social and physical research traditions. Specifically, statistical correlation provides a common language and concepts between social and physical scientists, a foundation for collaboration. Unfortunately, statistical correlation also exposes the weak measurement conventions of contemporary social science research, which erode and undermine common goals.

Unlike the theoretical architecture of physical science, which is built on a foundation of objective, linear measures, social sciences remain fixated on ordinal raw scores and ratings. Broadly across the social sciences, researchers are deeply committed to measurement with “assumed” rather than objective properties, which is simply anathema to physical science collaboration. The function of objective, international measurement standards in physical science makes folly of conventional social science measurement practices. Sensitivity among social scientists to weak measurement has led to important advances such as generalized linear models (GLM) [5], but support for them is restricted, and social researchers typically find GLM too complicated for ordinary applications.

An objective of present research was to demonstrate a simple linear probabilistic measurement model, which addresses social science measurement limitations. This demonstration establishes a common language between social and physical constructs and, implemented broadly, would improve possibilities of effective collaboration.

Results from present, ongoing research demonstrates simple mathematical parameterization with a Rasch model, which clarifies axiomatic foundations of a real number scale. Measuring units in this framework were shown to have Euclidian properties necessary to represent both physical and social observations in a common metrological framework. Then hierarchical statistical methods examined theoretical coherence of a psychophysical construct in this context. A practical effect here is to render the long standing bifurcation into social and physical sciences certainly less meaningful, and, arguably, unnecessary.

More specifically, an experiment was conducted that compared subjective self-confidence ratings of mothers caring for children supported by complex medical technologies. One group received specially designed simulation training, while another group participated in conventional, instructor-led hospital-based training. A functional caregiving construct representing mothers’ confidence was operationally defined with physical tasks, which were intended to manifest a quantitative performance gradient. Those mothers more confident about caring for their children supported by medical
technologies were expected to demonstrate significantly higher confidence on the measurement construct, and overall probabilistic measures were compared between training groups.

4. Methods

4.1. Sample
Participants consisted of all caregivers enrolled in supervised training at Riley Children’s Hospital at Indiana University Health (N = 70). While infant tracheostomy patients ranged from one month to 17 years, primary caregivers were typically parents. All participants were from American Midwestern states and predominantly with English language background.

4.1. Data
Both competency and confidence observations using standard rating scales were collected. Caregiver competency was scored on several tasks central to hospital-led training. For example, performance tasks such as “Alleviate respiratory distress for a child with a tracheostomy” and “Perform CPR on a child with a tracheostomy” consisted of several discrete steps, which were scored dichotomously (0/1). Caregivers reported self-confidence ratings using items with rating scales (1 = none, 2 = a little, 3 = somewhat, 4 = a lot, and 5 = completely).

4.2. Analysis
Competency and confidence ratings were transformed to linear measures with a Rasch model for rating scales and results were reported in both raw form (scores and ratings) and linear logits (log odds units). Instrument reliabilities of all psychometric measures exceeded conventional standards, that is, alpha >= .80.

4.2.1. Measurement model. Raw rating responses were first transformed to linear units (log-odds) with Winsteps software for Rasch measurement [6], then differences between item difficulties and caregiver’s confidence were modeled with one parameter logistic function, which established a common real number scale for items and caregivers. The mathematical model for the raw data transformation is:

\[
\Pi_{n\in\mathbb{X}} = \frac{\exp \sum_{j=0}^{x} \left[ \beta_n - (\delta_i + \tau_k) \right]}{\sum_{k=0}^{m} \exp \sum_{j=0}^{k} \left[ \beta_n - (\delta_i + \tau_k) \right]}
\]

Where \( \beta \) = caregiver’s confidence, \( \delta \) = task difficulty, and \( \tau \) = rating scale thresholds. \( \Pi_{n\in\mathbb{X}} \) is the probability that any item \( \delta_i \) will be rated \( X \) by caregiver \( \beta_n \) where \( X \) takes a value from a fixed range (1 = none, 2 = a little, 3 = somewhat, 4 = a lot, and 5 = completely).

Dichotomous competency scores were transformed with a Rasch model for achievement scales [7].

4.2.2. Measurement properties. Transformation of caregiver self-confidence ratings to linear measures were evaluated with appropriate separation indices and fit statistics, as well as conventional psychometric reliability. A comparable evaluation was conducted with competency scores.

4.3 Conventional statistical analyses. Competency and Confidence were statistically compared in a 2 X 2 within group MANCOVA with repeated measures, which controlled for age, language, and gender covariates. Model assumptions concerning normality, linearity, additivity, and independence were examined. Standardized effect sizes were computed to represent group differences. Contributions
Figure 1. Functional caregiving experiment to validate physical implications of simulation training.

Figure 2. Physical caregiving challenges increase as caregivers and children advance from homes into neighbourhoods, communities, and urban areas. Social-cultural context defines specific skills caregivers need at each level. Measurement on a linear scale clarifies probabilistic differences in caregiving difficulty as complexity increases across the continuum.
Mothers’s confidence ratings and item difficulties are represented here in a framework that describes probabilistic relations between perceived task difficulties and caregiver confidence. Results are presented after participation in medical technology simulation versus instructor-only led training to caregiver self-confidence after traditional hospital-led training versus experimental training (hospital-led + simulation) were also examined with the following model: $Y = \text{Caregiver confidence}$, $X_1 = \text{Confidence after initial training (scale values)}$, $X_2 = \text{Confidence after simulation training (coded for simulation and control groups)}$, when:

$$Y = a + b_1 X_1 + b_2 X_2 + e$$

Then, significant change in $R^2$ between caregiver self-confidence attributable to training + simulation confidence, when controlling for age, language, and gender compared to hospital training only clarified effectiveness strength of simulation training. Figure 1 presents the study design.

5. Results
Figure 2 presents an idealization of qualitative physical performance goals in an objective scientific framework. Figure 3 presents their parameterization in a common framework for caregivers’ self-confidence and perceived physical task difficulties. Both mothers’ confidence ratings and physical task difficulties defined a caregiving construct that was mathematically transformed to common logit units. Therefore, objective probabilistic relations can now be expressed about mothers’ confidence to complete specific caregiving tasks. Likewise, caregiver confidence measures can be aggregated by groups to establish effect sizes. Moreover, ongoing observations are incrementally increasing the capacity to investigate the dynamics underlying mothers’ confidence and better understand the conditions that promote mothers’ confidence to implement medical technologies in their homes.

As expected, caregiving tasks defined a coherent empirical variable, which described mothers’ confidence to care for children with medical technology. Moreover, the physical task hierarchy conformed to predictions concerning qualitative caregiver shifts across a humanistic construct.

6. Discussion

A goal of this research was to demonstrate that objective linear units contribute to transparent communication among disciplines in scientific research programs, which should improve understanding and facilitate problem solving in collaborations. Results presented here show human self-perceptions parameterized on probabilistic linear scales corresponded directly to physical performance expectations, both defined by objective thresholds also expressed in linear units. This framework mediated parallel social and physical research paradigms, which mitigate those differences that typically stymie collaboration. An important outcome here was empirical analysis meaningful to both physical and social perspectives. These results suggest the traditional bifurcation of physical and social observations need not have central importance to scientific problem solving.

Finally, this facilitation of research between social and physical sciences could logically have been accomplished with alternative mathematical approaches to metrology. However, the measurement system implemented here, arguably provided an efficiency, convenience, and transparency currently not widely prevalent in the social sciences.

6.1. Implications

First, these results show simple linear measurement methods are already available for representing social and physical observations in common frameworks with objective linear properties. Common thresholds on this framework can now be articulated between social-behavior and physical science targets. In addition, the strong properties of this framework support meaningful and convenient measurement of change, which is typically only assumed in weaker social science paradigms. These advances have broad implications across health and biological sciences where integration of social constructs is desperately needed. An integration of physical and social methods is already documented in numerous laboratory studies and broader applications should be considered of those advances.

7. References

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