Diversity Measurement: Steps towards the Measurement of Interdisciplinarity?

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In his reaction to our recent article about diversity measurement in *Journal of Informetrics* (Leydesdorff *et al*., 2019), Rousseau (2019) considers *DIV* as an acceptable diversity measure that needs further refinement. *DIV* improves on Rao-Stirling diversity Δ (Rao, 1982; Stirling, 2007) or its modified version ${}^2D^3$ (Zhang *et al*., 2016) because *DIV* meets, among other things, Rousseau's (2018) "monotonicity" requirement. Rousseau (2019) proposes *DIV** = *N.DIV* as an improvement: *DIV** additionally meets the "effective number requirement" of Leinster and Cobbold (2012) and thus measures "true" diversity. Using "true" diversity, one is allowed to compare scores in terms of ratios or percentages (Zhang *et al*., 2016, p. 1259).

1. We welcome the improvement. *DIV** scales also better than *DIV* because of the multiplication by *N*. (*DIV* tends to become very small because three terms bounded between zero and one are multiplied.) We incorporated *DIV** (alongside *DIV,* Δ, and ${}^2D^3$) into the standard output of the software at http://www.leydesdorff.net/software/mode2div. Additionally, the software for overlay-mapping in terms of Web-of-Science categories (at https://www.leydesdorff.net/wc15) now routinely provides these diversity measures.

2. We agree with Rousseau's (2019) further objection that "disparity is just a relative (normalized) sum" in *DIV*, but our conclusions are different: indeed, the weights are no longer taken into account within the term representing disparity if the Simpson diversity measure is decomposed into separate indicators for variety and balance. Thus, one loses information when compared with RS diversity.

   If so wished, the weights can be brought back in by formulating as follows:

$$DIV^* = n_c * (1 - Gini_c) * \sum_{i=1, j=1, i \neq j}^{i=n_c, j=n_c} p_i p_j d_{ij} \qquad (1)$$

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However, evenness is then counted twice (Rousseau, *personal communication*, 6 March 2019). Following Stirling (2007, p. 712), one could go even further in this direction and add exponents in order to balance the components differently, as follows:

$$\Delta = \sum_{ij, i \neq j} (d_{ij})^{\alpha} (p_i p_j)^{\beta} \tag{2}$$

Or analogously in the case of *DIV**:

$$DIV^* = n_c * (1 - Gini_c)^{\alpha} * \sum_{i=1, j=1, i \neq j}^{i=n_c, j=n_c} (p_i p_j)^{\beta} (d_{ij})^{\gamma} \tag{3}$$

Stirling (2007) added to his discussion of Eq. 2: "If exponents α and β are allowed to take all possible permutations of the values 0 and 1, this yields four variants of the heuristic Δ." In his Table 2 (at p. 712), Stirling (2007) identifies "disparity" with $\alpha = 1$ and $\beta = 0$. Combining both factors *ex ante* ($\alpha = 1$ and $\beta = 1$) provides his definition of "diversity." Furthermore, Stirling (2007, at p. 711) formulated ten criteria for further developing diversity measures. Among these, the criterion of "explicit aggregation" is formulated as follows: "*Δ* permits explicit aggregation of variety, balance, and disparity, by reflecting divergent contexts of perspectives using weightings" (2007, at p. 711). Taking the *value* of "disparity" into account, as suggested by Rousseau (2019) and, for example, formulated by us in Eq. 1, would violate this requirement of explicitness because "disparity" and "diversity" are then related in the definitions or, in other words, *ex ante*.

The exponents in Eqs. 2 and 3 make the parameter spaces very large. For reasons of parsimony, we prefer the original formulation of *DIV* with the modification (*DIV** = *N*.*DIV*), as follows:

$$DIV^* = n_c * (1 - Gini_c) \ * \sum_{i=1, j=1, i \neq j}^{i=n_c, j=n_c} (d_{ij}) \tag{4}$$

3. Otherwise, we agree with Rousseau that one cannot expect that a single measure meets all requirements. Betweenness centrality, for example, provides a relevant, but very different measure of inter-, multi-, or transdisciplinarity (Leydesdorff, 2006; Rafols & Meyer, 2010, p. 265; Rafols *et al*., 2012; cf. Otte & Rousseau, 2002). The crucial difference between *Δ* and ${}^2D^3$ on the one side, and *DIV* and *DIV** on the other, is the factor (1 – *Gini*) in the definition of the latter two indicators as an *explicit* operationalization of evenness (Nijssen *et al*., 1998). One can expect large differences between measuring diversity with ${}^2D^3$ or *DIV** in empirical applications.

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