Richard Dawid's String Theory and the Scientific Method

String Theory Background (1.1):

Following the unification of three out of four fundamental forces, namely, electromagnetic, weak, and strong forces, in the Standard Model (SM) of elementary particles in the 20th century, there was a major push to integrate the final force, gravity, into particle dynamics. Quantum field theory (QFT) emerged as a search for the "Grand Unified Theory" (GUT) that could reconcile quantum mechanics (QM) with gravitation (QG). Characteristic calculations of QFT involve summing up all possible patterns of particles emitted and absorbed in particle interaction processes. Although these sums include terms with infinitely large forces, finite counter-terms can be introduced to yield tractable solutions. This mathematical counter-balancing of finite and infinite terms is called Renormalization. Renormalization calculations result in the well-defined finite observable quantities of the SM…*except* when gravity is included. String theory (ST) attempts to solve the problem of the non-renormalizability of quantum gravity by "extending" the contact-point between any two particles as strings and hypothesizes that observable matter particles arise from their oscillations and topological distortions in 10 space-time dimensions. ***Thus, the introduction of extended elementary objects and of extended dimensionality is an entirely mathematical choice made by physicists to allow for tractable and finite QFT calculations with QG.***

Scale, Dimensionality, and Measurability (1.1):

String theory's two main conditions face significant obstacles. The string scale lies about ~13-14 orders of magnitude beyond the energy scale testable at the Large Hadron Collider (LHC). Only four space-time dimensions can be macroscopically measured, while the other six are assumed to be "compactified". In addition to these, ST also faces the challenge of incompleteness. Although ST is self-consistent as a mathematical expansion of particle interaction processes, the physics driving the general theory behind this expansion and the size of the expansion parameter (the way in which the strings couple) is unknown. Duality relations such as T-duality, M-theory, Ads/CFT correspondence attempt to characterize patterns of string coupling and their empirical signatures. These relations have yielded possible extensions to the SM such as Supersymmetry and Eternal Inflation, but no specific calculations have been made. ***String theorists face the immense challenge of 1) characterizing the structure and scope of ST, 2) theoretically predicting the empirically measured values of the SM, and 3) empirically verifying ST.***

Three Contextual Arguments for the Viability of String Theory (1.3):

1) **The No Alternatives Argument (NAA) (pg 31-33):**
    a) There is a wide consensus that at the scale of the SM, treating particles like points is incorrect.
    b) Competing theories of ST either appeal to insufficient physical principles or do not convincingly account for a).

c) If they do account for a), then they univocally collapse into ST.
d) If they appeal to insufficient physical principles, then they fail.
e) Since no alternative theories have come up despite intensive search, ST is the only viable option.

2) **The Unexpected Explanatory Coherence Argument (UEA) (pg 33-35):**
   a) ST introduced the extendedness of particles and of dimensions simply to join QM with gravitation.
   b) QM and gravitation are themselves supported by empirical evidence.
   c) ST not only joins QM with gravitation but *implies* them individually (ex: Y-M gauge theory, black hole entropy)
   d) ST also *implies* supersymmetry, which is an analog to classical symmetry.
   e) All of these unexpected explanations necessarily appeal to a).
   f) Thus, the unexpected explanations imply the viability of ST itself.

3) **The Meta-Inductive Argument (MIA) (pg 35-37):**
   a) ST was built in the tradition of the SM.
   b) The SM has had tremendous predictive success.
   c) Like ST, the SM was also created to solve conceptual problems related to structuring empirical data.
   d) Like ST, the SM also initially had no empirical confirmation.
   e) Like ST, NAA and UEA also applied to the SM.
   f) Eventually the SM was empirically proven to be empirically successful.
   g) Since, scientific theories developed in the tradition of SM (c-e), *tend* to be empirically successful once tested, ST is viable.

Empirical Evidence vs Non-Empirical Evidence (pg 38):
EE - Evidence supports the theory *and* the theory predicts evidence.
NEE - Evidence supports the theory but theory *does not* predict the evidence.

Classical Scientific Theory Assessment Criteria (pg 22, pg 42):
1) Theory must reach a largely complete theoretical state.
2) It must be internally consistent.
3) It must be able to quantitatively predict empirical data.
4) It must undergo empirical testing to determine whether to continue further work. *Rational analysis on its own is not an alternative to empirical testing*.
Problems (pg 43):
1) *Kuhn:* Even the interpretation of empirical data always happens within some scientific paradigm choice informed by conceptual, theoretical, and social elements.

2) *Laudan:* Since scientists judge the status of their theories based on *both* empirical *and* theoretical qualities. Thus, EE and NE should have equal footing.

Dawid's Scientific Theory Assessment Proposal:
Scientific Underdetermination (SU) and its Limitation (pg 44-47): Scientific arguments can be classified more generally as ***ampliative arguments***, namely arguments with conclusions that are more than "strictly" entailed by the premises. Ex: 1) Person A recovered after taking Advil., 2) Person B recovered after taking Advil., 3) Person B recovered after taking Advil., 4) Therefore, *probably* all people will recover after taking Advil. In addition to being ampliative, scientific conclusions are restricted by the *available evidence*. A scientific theory is said to be ***underdetermined*** when it is possible that there exist unknown theories which fit the given data equally well but predict different phenomena.Although we cannot absolutely predict the number of alternative theories that may explain a given data set, we can ***strongly limit*** the possibilities by assessing their viability by linking NAA, UEA, and MIA.

Dawid's Thesis:
(pg 47-50) Furthering Laudan's analysis, Dawid claims that theory assessment ought to be based on the assumption of limitations to scientific underdetermination. He asserts that it is possible to assess ampliative scientific underdetermination <u>without</u> knowing alternative theories. By assuming strong limitations to SU exist, one can strengthen the inferential connection between empirical data and theory. Dawid recasts NAA, UEA, and MIA in this light, referring to their conjunction under the umbrella of SU as Non Empirical Theory Assessment.

*****An important distinction to note is that Dawid not only refers to the limitation claims themselves but also the framework of claims (3.2)! He draws a fundamental relationship between the conditions of the science and the meta-conditions of the framework in which the science is performed.***

Discussion Questions (focus on pages 50-64):

1) **In Dawid's view, how can NAA, UEA, and MIA successfully limit the scientific underdetermination of String Theory? What are the non-empirical criteria?**

2) **What is the nature of the inferential leap one can make via MIA in order to justify the viability of String Theory?**

3) **When do the NAA, UEA, and MIA break-down in the non-empirical framework?**