1. Introduction

The integration of the fields of philosophy of science and history of science into a single, unified discipline (the history and philosophy of science, or HPS) arose out of the observation that a full-bodied philosophical analysis of science cannot possibly be done without diving into its history, and vice versa – that historic episodes of science cannot be fully understood without investigating the philosophical questions that preceded them.

This sentiment was perhaps most famously echoed by Thomas Kuhn in his influential monograph, *The Structure of Scientific Revolutions* (1970). In *Structure*, Kuhn urges us to view these historic episodes not in relation to our modern theories, but instead in relation to the theories of the time. (Kuhn, 1970, p. 3) The upshot of this recontextualization was a radical transformation in the way scientific progress was viewed – by placing landmark achievements in historical context, philosophers of science have since turned away from the "development-by-accumulation" view, (Kuhn, p. 2) and towards a view that sees scientific progress as an oscillation between periods of "tradition-bound" 'normal science' and "tradition-shattering" 'revolution'. (Kuhn, p. 6)

In more recent years, Hasok Chang has identified what he calls "an acute dilemma about normal science" (Chang, 2004, p. 236) and has advocated for HPS as a solution to this worry. In *Inventing Temperature* (2004), Chang puts forth the consideration that HPS may be used as a 'complement' to specialist normal science, by revisiting "useful ideas and facts lost in the record of past science". (Chang, p. 237) In this way, HPS as 'complementary science' may function not only to recover these relics, but also to deepen our understanding of current science, and even provide new insights into future lines of development. (Chang, p. 237)

Perhaps as a consequence of the definition of 'normal science,' Chang does not explicitly advertise complementary science as a way to retrieve past knowledge *across* scientific disciplines. He does not, in other words, treat complementary science as an *interdisciplinary* enterprise that looks at the ideas of *multiple* disciplines throughout history. I believe, however, that complementary science is a sufficiently flexible tool for just this job. In this paper then, I seek to expand Chang's notion of complementary science by showing how an interdisciplinary approach may be a more effective method of meeting the aims set out by his original view. Ultimately, this 'broad' approach will offer a richer understanding of nature by allowing the

complementary scientist to take a bird's-eye view of scientific and philosophical considerations across both history and science itself.

In the next section, I will provide a bit of exegesis with the aim of clarifying Chang's position in relation to Kuhn, beginning with a brief description of Kuhn's concept of 'normal science'. I then outline Chang's primary concern regarding normal science and go into some detail about the motivations and objectives for HPS as a 'complement' to normal science. In Section 3, I will identify a new area of application for complementary science, namely the integration of past knowledge from *multiple* disciplinary sources. I will then show how this 'broader' method possesses an enhanced ability to achieve the main objectives of complementary science as outlined by Chang's 'narrow' approach: i) the reduction of dogmatism, ii) the promotion of pluralism, and iii) the generation of 'genuinely novel' kinds of knowledge. I conclude in Section 4.

2: What's Wrong with Normal Science?

In *The Structure of Scientific Revolutions* (1970), Kuhn defines 'normal science' as "research firmly based upon one or more past scientific achievements […] that some particular scientific community acknowledges for a time as supplying the foundation for its further practice." (Kuhn, 1970, p. 10) Normal science is what happens then, when scientists unite under a common set of guiding principles for scientific practice. These principles typically include theories, methods, and observations, and they set the parameters for the kind of problems that the 'normal' scientist should expect to encounter, as well as what counts as valid solutions. (Kuhn, p. 10; Andersen, 2019, personal communication)

As a consequence of the mutual agreement of principles within a 'normal' scientific community, work may only proceed if the community agrees to commit to certain 'fundamental' principles without question. As Kuhn puts it, "when the individual scientist can take [these principles] for granted, he need no longer, in his major works, attempt to build his field anew, starting from first principles and justifying the use of each concept introduced." (Kuhn, pp. 19-20) And, per Chang: "many elements of knowledge [in normal science] must be taken for granted, since they are used as foundations or tools for studying other things." (Chang, 2004, p. 237)

It is this blind acceptance of principles that Chang takes as central to the "acute dilemma" for normal science. (Chang, p. 236) On one hand, normal science *must* protect "certain fundamentals and conventions" from skepticism in order to facilitate continued progress. (Chang, p. 236) On the other hand, this uncritical attitude is a perfect recipe for dogmatism – which Chang, following Karl Popper, believes is ''a danger to science and, indeed, to our civilization,'' since science so often informs our societal practices. (Popper, 1970, as cited in Chang, 2004, p. 237)

Chang offers a potential solution to this riddle of normal science in the form of 'complementary science' – a study which aims to question those ideas taken for granted in normal science by exploring past systems of knowledge, which have, for one reason or another, been abandoned in the course of scientific history. (Chang, p. 237) It should come as no surprise that complementary science marks a further integration of the fields of history of science and philosophy of science. The complementary scientist necessarily employs both philosophical and historical methods of inquiry in his work – for a thorough skepticism about those 'untouchable' principles in normal science would not be possible without philosophy, and an identification of the relevant questions and answers regarding them would be similarly impossible without a deep dive into the historical record. (Chang, p. 240)

The first directive of complementary science then, is to challenge the 'unquestionable' theories, methods, and observations that ground normal scientific practice. As a natural by-product, this skepticism allows complementary science to generate the kinds of scientific knowledge that normal science cannot. (Chang, pp. 237, 249) The most valuable form of such knowledge that Chang identifies is what he calls "genuinely novel knowledge" – that is, knowledge that sets a direction for new experimental or theoretical developments. (Chang, pp. 245-247) I take the production of new knowledge to be the second main objective of complementary science.

In articulating his approach, Chang makes great strides to emphasize that complementary science "is inherently a pluralistic enterprise" and that no source of knowledge should be off-limits for study, no matter the divergence from the current orthodoxy. (Chang, p. 247) This seems to me to be the third goal of complementary science – to promote a diversity of the sources of knowledge available for scientific investigation.

It also seems to me, however, that there is still more to be said about pluralism's role in complementary science. For a mode of study that is 'inherently' pluralistic, Chang is apparently quiet on complementary science's application across *multiple* scientific fields. In other words, he does not advocate for an *interdisciplinary* complementary science. In my view, this is an oversight – if the goals of complementary science are to reduce dogmatism, produce novel ideas, and promote pluralism, then surely the complementary scientist does not wish to resign herself to a single area of study. Rather, I believe that it is in the best interests of both the scientist and HPS as a whole to achieve the biggest-picture understanding possible, which cannot be done without drawing from multiple, diverse fields of study.

In the following section, I will run with this line of thinking and argue in support of a 'broad' interdisciplinary version of complementary science, and ultimately show that the broad approach can be more effective than the traditional 'narrow' approach at reducing dogmatism, promoting pluralism, and generating genuinely novel kinds of knowledge.

3: Interdisciplinary Complementary Science

Having now seen that the main objectives of complementary science are to: i) reduce dogmatism, ii) promote pluralism, and iii) generate novel knowledge, I will now propose an expanded notion of complementary science that, I hope to show, enhances its ability to hit these targets.

What I suggest is an *interdisciplinary* approach that aims to question the taken-for-granted ideas of normal science by browsing across the shared matrix of science and history, picking out relevant items of knowledge, and piecing them together in order to build a clearer, fuller picture of the particular object of investigation. Following Chang, this 'piecing together' may either consist in the extension of "experimental knowledge," (Chang, p. 246) such that a forgotten experimental procedure from one discipline is modified to include aspects of a forgotten procedure from another discipline; or it may consist in the integration and development of theory, (Chang, pp. 246-7) wherein long-lost ideas from two (or more) disciplines are assimilated.

In the following discussion, I will give support to this 'broad' interdisciplinary flavour of complementary science (in contrast to Chang's more 'narrow' approach) by showing how it is a more effective method of achieving the objectives aimed at by the narrow view.

Reducing Dogmatism

In the first place, any 'normal' interdisciplinary study of a phenomenon seeks to reduce dogmatism. By drawing from multiple scientific perspectives, the specialization inherent in each normal scientific discipline is offset by the specializations of the others – the normal scientist, who, until then, had only been exposed to the "rigorous and rigid" (Kuhn, 1970, p. 5) assumptions of her discipline is now exposed to fresh ways of thinking, which allow her to challenge these assumptions which she had previously taken as unquestionably true. This questioning of dogmatic principles is *precisely* what Chang had in mind for complementary science – it stands to reason then, that a broader, interdisciplinary take on complementary science can only result in a greater reduction of dogmatic beliefs and practices.

Promoting Pluralism

Chang takes the narrow view to be "inherently […] pluralistic". (Chang, 2004, p. 247) But it is pluralistic in only one specific sense – across *time*. Put another way, the narrow view takes multiple perspectives into consideration *only if they are temporally separated within a single discipline* – that is, only if they represent different *historical* perspectives. The broad view, on the other hand, promotes pluralism on an additional dimension – across *space*. More concretely, on the broad view, multiple perspectives may be considered if they also differ in terms of *content* (though they should still be, at least loosely, focused on the same object of investigation). On the broad view, temporal pluralism and spatial pluralism work together to enrich the scientific picture by picking out elements across both history and science itself.

Generating Novel Knowledge

Widening the scope of complementary science to include past knowledge across multiple disciplines does, at least, two things to stimulate the production of new knowledge. Firstly, it deepens the pool of knowledge available to the complementary scientist. She becomes free to cross scientific borders without, as it were, needing a passport. The entire catalog of scientific endeavour is up for grabs, and as a result, the complementary scientist may find new avenues for development in unlikely and unexpected places.

Secondly, it allows for a big-picture understanding of the object of investigation. It is overwhelming likely that many researchers from many different disciplines have asked similar (or even identical) questions about the object over the years. The complementary scientist who chooses to borrow ideas from each of these sources will end up with a highly detailed and nuanced view of the object that she could not have possibly developed if she had confined herself to the historical record of a single discipline. With such a comprehensive understanding in hand, one would be hard-pressed *not* to generate some kind of novel knowledge.

4: Conclusion

I hope to have shown in this paper that an interdisciplinary approach to complementary science not only supports, but *enhances* its ability to reduce dogmatism, promote pluralism, and generate novel knowledge. I suspect that Chang did not himself promote this interdisciplinary stance because of complementary science's role in counter-balancing normal science – which is inherently confined to a single discipline. But given complementary science's pluralistic and anti-dogmatic aims, I find it somewhat myopic to have it operate within the same limits. Normal science is rigid and *must* proceed within a single discipline. But complementary science is flexible and has the freedom to explore the scientific record across both history and specialization. I fully believe that the natural next step for complementary science is to embrace this fact.

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